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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 181.

B. T. GALLOWAY, *Chief of Bureau.*

THE CURLY-TOP OF BEETS.

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U. S. Department of Agriculture

BY

HARRY B. SHAW,

Assistant Pathologist in Cotton and Truck Diseases and
Sugar-Plant Investigations, in Cooperation with
the Bureau of Entomology.

Issued July 13, 1910.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1910.

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181

[Continued on page 3 of cover.]

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181

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., February 25, 1910.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 181 of the Bureau series a manuscript entitled "The Curly-Top of Beets," by Harry B. Shaw, Assistant Pathologist in Cotton and Truck Diseases and Sugar-Plant Investigations of this Bureau, in cooperation with the Bureau of Entomology.

The sporadic outbreaks of this disease have caused much loss to sugar-beet growers in our Western States during the past ten years. Curly-top has been under investigation by this Bureau since 1902, and Bulletin No. 122 of this Bureau, by Dr. C. O. Townsend, was published in 1908 to show the lack of proof that bacteria, fungi, or unfavorable environmental conditions were the cause of curly-top. Since that date Mr. Shaw has proved that the disease results from the punctures of an insect, a theory previously advanced by Dr. E. D. Ball, then special agent of the Bureau of Entomology. This group of plant diseases, another example of which is stigmonose of carnations, described by Mr. A. F. Woods in Bulletin No. 19 of the Division of Vegetable Physiology and Pathology, is of special interest to the plant pathologist on account of the physiological problems involved, but the practical control of these troubles must be based largely upon studies by the entomologist.

To make this discussion of curly-top more complete and of greater practical value Mr. Shaw has included a description of the beet leafhopper and its life history, largely drawn from the work of Dr. E. D. Ball, whose assistance, and that of Dr. F. H. Chittenden, of the Bureau of Entomology, is gratefully acknowledged.

Further knowledge of the most effective means of control is hoped to result from studies planned in cooperation with the Bureau of Entomology.

Respectfully,
G. H. Powell,
Acting Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

	Page.
Introduction	9
Symptoms of curly-top	9
External symptoms	9
Internal symptoms	11
Symptoms in seed beets	12
Only one symptom really characteristic	13
Cause of the disease	13
Theories	13
Preliminary experiments	13
Isolation cages	14
Nymph of beet leafhopper more harmful than the adult	18
History of an outbreak of curly-top in the experimental field at Garland, Utah	18
Early sowing advantageous in preventing curly-top	19
Extraction of plant juices not sufficient to account for the disease	20
Conditions favoring an outbreak of curly-top	21
Natural and artificial barriers to leafhopper invasion	22
Host plants of Eutettix tenella	22
Description of the beet leafhopper	22
Beet growers should be able to recognize the leafhopper	24
Serious nature of curly-top	24
A consideration of curly-top in seed beets	24
Several types of leaf-curl on seed and sugar beets	28
Affected seed beets almost nonproductive	29
Percentage of loss of seed beets	29
Severe outbreaks not frequent in a locality	31
Progeny of the diseased seed beets healthy	31
General character of curly-top	31
Summary	33
Conclusion	35
Recommendations	36
Bibliography	37
Description of plates	42
Index	43

ILLUSTRATIONS.

PLATES.

Page.
Plate I. Fig. 1.—Beet leaves affected by curly-top; also a beet leafhopper. Fig. 2.—Dock leaf spotted by punctures of beet leafhopper. 42
II. Fig. 1.—Sugar-beet seedlings and leaves in a healthy condition and others affected by curly-top. Fig. 2.—Healthy and curly-top sugar beets of medium size.......... 42
III. Fig. 1.—Large sugar beet affected late in the season by curly-top. Fig. 2.—Sections of healthy and curly-top sugar beets, showing the discoloration of fibro-vascular bundles 42
IV. Fig. 1.—Seed beet exhibiting inward type of curl. Fig. 2.—Seed beet with long, sinuous type of leaves caused by curly-top 42
V. Fig. 1.—Seed beet showing retracted type of curl. Fig. 2.—Seed beet showing both inward and retracted type of leaf-curl and seed beet with rosette of severely retracted leaves and no seed stem.......... 42
VI. Fig. 1.—Curly-top seed beet maturing seed. Fig. 2.—Seed beet slightly affected by curly-top.......... 42
VII. Healthy seed beet of same age as that shown in Plate VI, figure 2. 42
VIII. Fig. 1.—Seed beet badly affected by curly-top and root almost destroyed by rot. Fig. 2.—Seed beet with sound root, though badly affected by curly-top 42
IX. Fig. 1.—Two young sugar beets showing curly-top symptoms under test conditions with leafhoppers. Fig. 2.—Portion of a cabbage leaf showing curly-top symptoms after leafhopper attacks......... 42

TEXT FIGURES.

Fig. 1. Healthy sugar beets, Vilmorin type 10
2. Curly-top sugar beet, face of leaves, showing retracted type of curl.... 11
3. Curly-top sugar beet, dorsal surface of leaves; the same plant shown in figure 2 12
4. Isolation cage and Mason jars for isolating sugar-beet plants.......... 15
5. Another type of isolation cage 15
6. A simple method of preparing iron hoops for cages, etc.......... 16
7. Mature healthy seed beet.......... 26
8. Sugar-beet seed stems showing curly-top symptoms.......... 27
9. Average seed yield of healthy and curly-top sugar beets 30

B. P. I.—563.

THE CURLY-TOP OF BEETS.

INTRODUCTION.

Through various publications the serious nature and general character of the curly-top of beets are fairly well known, either under that name[a] or more locally as "blight," "western blight," or "whiskered beets." These names are descriptive of one or another of the symptoms manifested by the stricken plants. Apparently no kind of beet is immune.

Recent experiments and observations have demonstrated not only the primary cause of this disease, but that it is an even greater menace to the production of beet seed than to the culture of beets for sugar.

SYMPTOMS OF CURLY-TOP.

EXTERNAL SYMPTOMS.

The external symptoms of curly-top are numerous and may be found in all parts of affected plants. Commonly the earliest to appear is an inward curling of the inner leaves from the entire margin toward the midrib. Almost simultaneously a distortion of the veins of the affected leaves may be noted; these become crinkled and knotted on the dorsal surface of the leaf (Pl. I. fig. 1, and Pl. II, fig. 1). As the disease progresses more leaves, and finally the whole plant, become involved; nipple-like protuberances develop on the veins, sometimes to the length of about three-sixteenths of an inch; and the whole leaf becomes tightly curled from either side. The petioles remain much shorter than in the normal plant (fig. 1) and become bowed, with the concavity inward; the crown is generally quite perceptibly wider than in the healthy beet, owing largely to an abnormal growth of small and imperfectly formed leaves outside of and around the original set of leaves; and the leaves and petioles bunch closely together instead of opening out and spreading (Pl. II, fig. 2, and Pl. III, fig. 1).

---

[a] "Blight" is used in so many other connections that it is deemed better to avoid its use in this paper; neither is "curly-leaf" considered quite as inclusive as "curly-top," since the latter term includes crown, petioles, leaves, and seed stems. However, it is acknowledged that "curly-top" is not an ideal name, because it fails to include the disturbances found in the root.

The foliage is generally of a dark, dull-green color and quite brittle, though thick and leathery in appearance. In severe cases, especially among young plants, the outer leaves soon become yellow, die, and turn brown; the inner whorls follow, until the entire plant is killed.

The roots throw out dense masses of rootlets from the two spiral grooves; hence the names "hairy-root" and "whiskered beets." (See Pl. II, figs. 1 and 2.) The root itself looks tough and fibrous and in many cases becomes sprangling. When pulled up, masses of soil cling to the hair-like rootlets and are with difficulty shaken off. The growth of every portion of the plant is checked, if not entirely arrested.

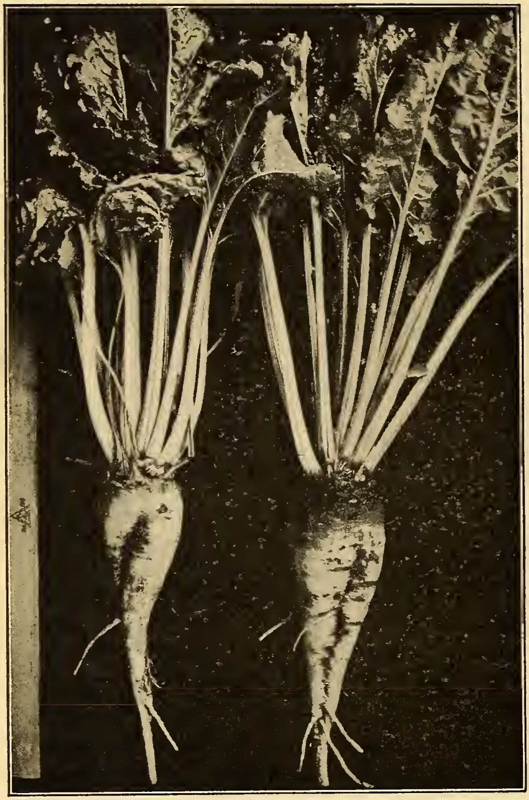

Fig. 1.—Healthy sugar beets, Vilmorin type. (For comparison with beets affected by curly-top.)

In many cases the leaf-curl assumes an alternative form. Instead of an inward curl, the leaf as a whole becomes strongly retracted and each portion between the larger veins is puffed out. This results in a blistered or "savoyed" effect. In this latter type the vein symptoms are not usually so pronounced. Sometimes the two types are combined; the leaf as a whole is then retracted, but the margin curls inward (figs. 2 and 3). Frequently wine-colored stains develop in the form of small circular spots over the surface of leaves of mangel-wurzels and garden beets, but no local discoloration has been noted on sugar beets except a faint mottling of young leaves which can only be seen by transmitted light.

INTERNAL SYMPTOMS.

Certain distortions of the cells of the tissues of leaf and stem have been observed in beets affected with curly-top; the fibro-vascular bundles may become darkened throughout the entire length of the root (Pl. III, fig. 2). No decay or softening of the tissues has been noted as a direct consequence of the disease: on the contrary, the root becomes tougher and more fibrous, thus rendering the slicing of the beets more difficult, with frequent clogging of the cutters. In many roots a blackened area, or even a cavity with black walls, may be found in the interior of the crown (27[a]) (Pl. III, fig. 2); this latter symptom may, however, be found under other conditions (3, 9, 11, 13, 16, 24, 29) and is not considered characteristic of curly-top alone. Very young beets may be so severely attacked that they are killed before the symptoms have time to develop.

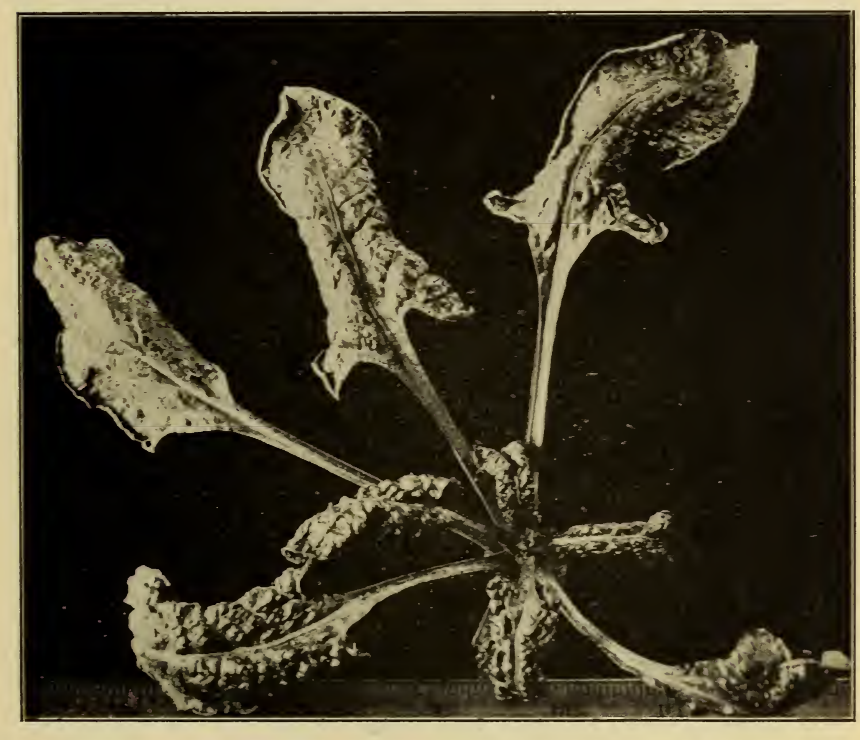

FIG. 2.—Curly-top sugar beet, face of leaves, showing retracted type of curl. Disease produced under test conditions by gradually increasing number of beet leafhoppers until curl developed. Plant at start three and a half months old.

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[a] The serial numbers in parentheses used in this paper refer to the bibliography on pp. 37–40.

SYMPTOMS IN SEED BEETS.

When beets are grown a second season for the production of seed the symptoms of the plants affected with curly-top are similar to those already described, but a much larger proportion of the retracted type prevails. In addition, many seed beets[a] are quite unable to develop seed stems; instead, the leaves gradually wither and the whole plant dies. In other cases feeble stems are produced which may or may not reach the flowering stage and then dry up and die; still others possess enough vitality, though badly dwarfed and stunted, to bear and mature seed (Pl. VI, fig. 1).

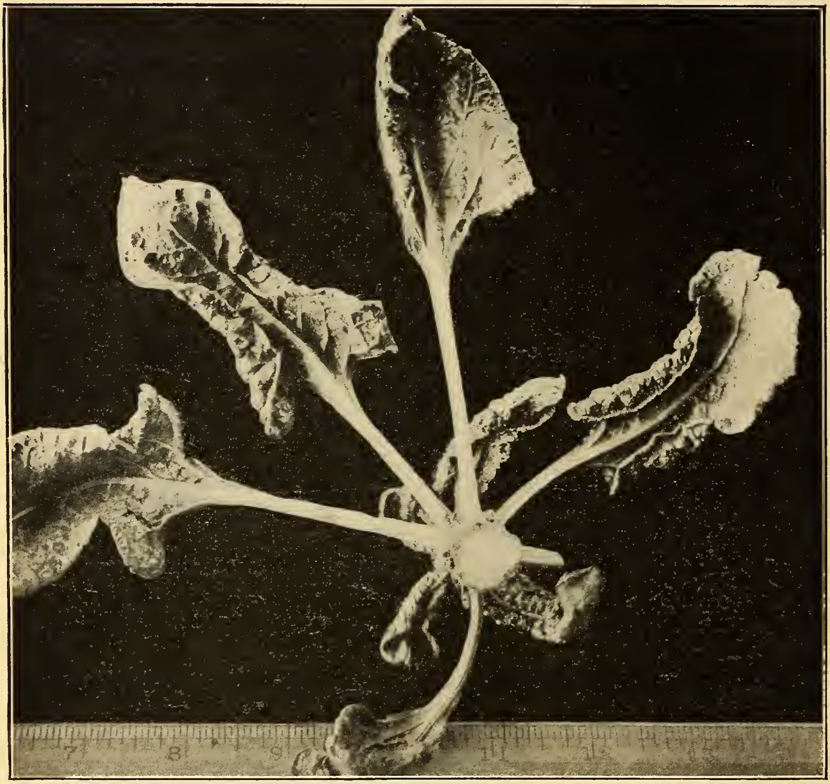

FIG. 3.—Curly-top sugar beet, dorsal surface of leaves; the same plant shown in figure 2.

Quite frequently the roots of seed beets affected with curly-top are found to have rotted areas of varying extent, sometimes involving the greater part of the root (Pl. VIII, fig. 1). This is not to be attributed to curly-top, but is probably brought about by the entrance of various organisms, such as *Phoma betae*, Rhizoctonia, etc. On the other hand, the root may remain sound and crisp, though the top may exhibit every symptom of a severe case of curley-top (Pl. VIII, fig. 2).

---

[a] While the term "mother beet" is probably the more familiar one, "seed beet" is considered better, inasmuch as beet flowers contain both male and female organs. The term "mother beet" implies that the flowers of the seed-bearing plant contain only the female organs.

ONLY ONE SYMPTOM REALLY CHARACTERISTIC.

It is to be remarked that most of the symptoms of curly-top, taken individually, may appear under other pathological or physiological conditions; so far as observed, the one real exception is the vein symptoms. However, the totality of the symptoms described in this connection has not been observed apart from curly-top.

CAUSE OF THE DISEASE.

THEORIES.

Until quite recently the cause of curly-top was unknown. Numerous theories have been advanced to account for it. Among the more plausible are the following: Bacteria, fungi attacking the leaves, fungi attacking the roots, insects, abnormal moisture supply, abnormal soil conditions, poor seed, and a combination of unfavorable conditions (26, 27).

After wide field observations Dr. E. D. Ball, then special agent of the Bureau of Entomology, stated (4, 5, 6) that in his opinion the disease is caused by the beet leafhopper[a] (*Eutettix tenella* Baker, Pl. I, fig. 1). Prof. E. G. Titus, formerly collaborator of the Bureau of Entomology, while engaged in entomological experiments observed the appearance of curly-top on beets in breeding cages in which some beet leafhoppers were found (6; also footnote, p. 23).

PRELIMINARY EXPERIMENTS.

The writer first turned his attention to the curly-top of beets late in the summer of 1907. Early in June of that year he had noted in the experimental field at Garland, Utah, a few cases of the disease among sugar beets. The earliest of these were among pedigree strains and among garden beets, both of which germinated and grew with much less vigor than the standard varieties of sugar beets. As the season advanced more cases appeared sporadically throughout the field.

---

[a] In this paper the beet leafhopper (*Eutettix tenella* Baker) will be referred to simply as the leafhopper.

Among the standard varieties there was apparently little difference in susceptibility. Several species of leafhopper were noted as being generally, though not abundantly, distributed over the field. A small lot of seed was sown in July; quite late in the season some of the seedlings were inclosed in a cheesecloth-covered cage to exclude leafhoppers and other insects.

No curly-top developed among the caged plants; some cases appeared in the open row. This experiment was of little value, because all of the plants had been exposed to insects for some time before any of the plants were isolated. Plans were then made to observe the beets with special reference to this disease from the outset of the following season.

With the beginning of the season of 1908 various experiments were started looking to the solution of this problem. These covered, in a preliminary way, almost all the ground suggested by the theories heretofore mentioned, with negative results so far as curly-top is concerned. The ground being thus cleared, the experiments were focused on the study of the effects of the work of certain sucking insects, notably thrips, red spiders, aphides, and leafhoppers, all of which were numerous in our field at Garland.

It was observed that each of these insects produced characteristic effects on beet leaves. At the outset it was deemed desirable to ascertain the specific effects of the attacks of each kind of insect upon beets. This was desirable not only to determine conclusively whether any of these might produce the curly-top symptoms, but, in case they did not, to know just what the effects of each might be. Since all of these insects abound on beets, it was necessary to be able to discriminate the work of each one from that of the others. Then, in case it was found impracticable entirely to exclude the tiny insects from beets isolated with leafhoppers, it might be easy to distinguish effects that could not have been produced by thrips, red spiders, or aphides. In practice it was possible to exclude all except a very few thrips, which entered the cages through the soil.

ISOLATION CAGES.

The construction of some of these cages will be understood on referring to figures 4 and 5. A foundation frame of $\frac{7}{8}$ by 6 inch lumber was used. This was sunk in the soil about 2 inches to prevent the entrance or egress of insects beneath the cage. Upon this foundation a frame of laths, stout wire, or $\frac{1}{4}$-inch soft iron rods bent into hoops was made (fig. 5). Over the frame was stretched loosely a covering of chiffon or silk veiling; then over that one of Brussels netting (figs. 4 and 5). The chiffon is impenetrable to the insects, but will not withstand the weather; the Brussels net is strong, but will exclude nothing smaller than adult leafhoppers; therefore both materials were used together. These covers were drawn well down the sides of the foundation frames and secured there by tacking laths over their free margins to the sides of the foundation frame. Special care was taken to make the corners tight. To place insects in the cage a lath was temporarily removed

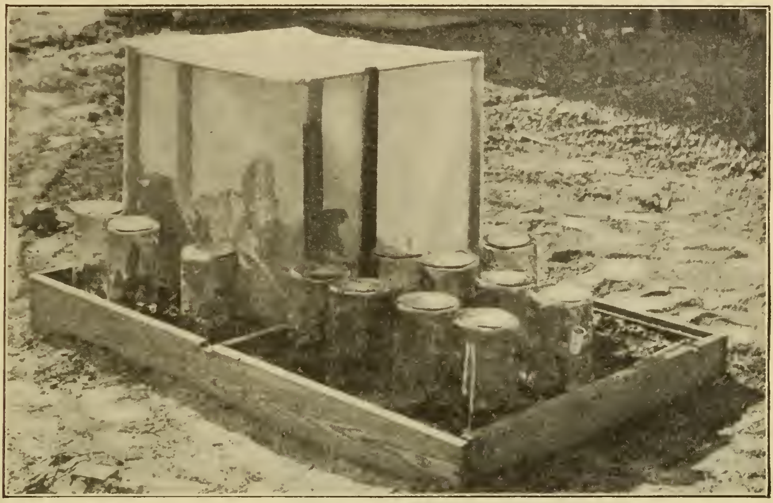

FIG. 4.—Isolation cage and Mason jars for isolating sugar-beet plants.

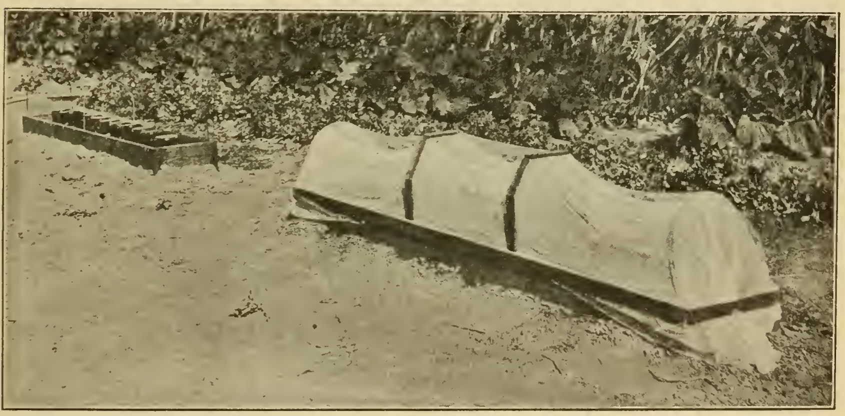

FIG. 5.—Another type of isolation cage.

from one side and the edge of the cover raised. The hoops of iron rod are especially useful for cages, covers, etc., and may readily be made by bending lengths of the rod over the edge of a board that has been cut to the proper size and shape, as shown in figure 6. It will be noted that the sides of this board are convergent. This is done to take up the resilience of the iron rod; otherwise the hoops would straddle too much.

In cages 1 and 2 a standard strain of beet seed was sown on July 18, and more on August 4. This germinated and grew under isolation conditions. Red spiders and aphides were excluded, but a few thrips gained entrance through the soil. Cage 1 was carefully partitioned into three insect-proof chambers. Colonies of thrips were introduced into chamber *a;* into *b* six adult beet leafhoppers were placed, and into *c* red spiders from the beets in the open field. Aphides were placed on beets in cage 3. Cage 2 was reserved as a "control." This was done on August 25; from that time the record of cage 1 is as follows:

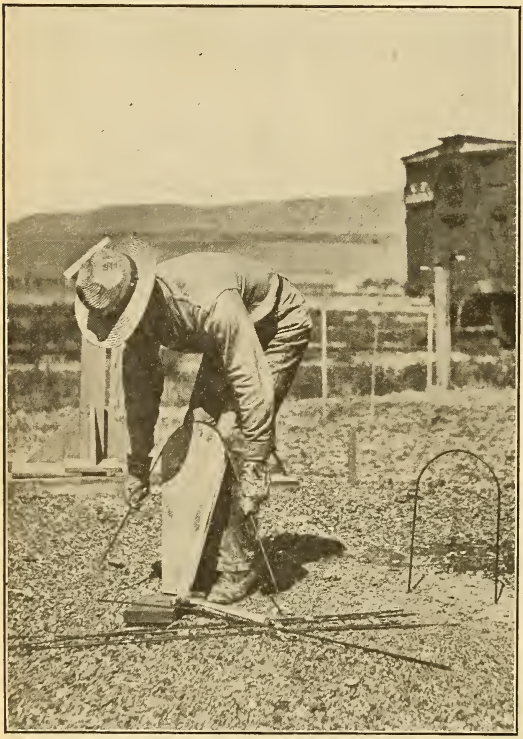

Fig. 6.—A simple method of preparing iron hoops for cages, etc.

August 28. Four more placed in *b*.

September 7. (*a*) Plants made good growth; leaves dark green, many of inner ones badly distorted, some being "savoyed" and some cup shaped by thrips' attacks. (*b*) Scarcely any growth made; leaves dull, leathery, and somewhat blotched or faintly mottled when seen by transmitted light; some leaves strongly concave; no vein symptoms. (*c*) Conditions similar to *a*.

September 8. Placed a few more hoppers in *b*.

September 12. (*b*) Four of the earliest sprouting seedlings show some curl on margin of inner leaves.

September 17. (*b*) Several more hoppers introduced. One leaf completely curled.

September 21. (*b*) Three plants show distinct curly-top symptoms on one or more leaves.

September 28. (*b*) Six plants affected with curly-top.

October 15. (*b*) All plants plainly affected.

None of the control plants became affected with curly-top, nor did any of those in compartments *a* and *c*. Most of the seedlings in this experiment were only about ten days above ground and possessed but two pairs of true leaves when the first hoppers were introduced. The first unmistakable signs of curly-top were noted within thirteen days after the introduction of leafhoppers.

In another frame beet seed had been sown on June 10; this frame was immediately covered with netting to exclude hoppers. Some preliminary experiments, already mentioned, were tried in this frame, but, as stated, with negative results so far as curly-top is concerned. The plants were simply checked in growth. On August 12 this frame was divided in the same way as cage 1. Compartment *a* was used for controls and *b* for the confinement of leafhoppers, and the plants in *c* were individually covered with inverted 2-quart Mason jars as follows: Nos. 1, 2, 3, and 10 with thrips; Nos. 6, 7, and 8 as controls; No. 4 with red spiders and thrips; Nos. 11 and 12 with red spiders; No. 5 with four leafhoppers; and No. 9 with two leafhoppers. At the beginning of this experiment these plants were two months old. The outer leaves were stripped off so that those remaining should not be too crowded under the jars. All the leaves left on the plants were immature, and in them active cell division was in operation. The record for this cage is as follows:

September 1. No. 5, inner leaves curing and vein symptoms showing (Pl. IX, fig. 1); all controls unaffected, except from confinement under glass.

September 4. No. 9, inner leaves curling and vein symptoms appearing; controls still normal.

In eighteen days curly-top symptoms appeared on the growing leaves of plants two months old at the start, with only four and two adult leafhoppers, respectively. Several days after the insects were imprisoned some of them became inoperative because they stuck to the wet walls of the jars. The plants were constantly bathed in moisture during this experiment.

On August 26 a cage was placed over a 2½-month beet. Four leafhoppers were placed in this cage. On August 30, four more hoppers were placed in this cage. On September 6, the inner leaves were curling and vein symptoms appeared. (See Pl. IX, fig. 1.)

Early in September some living beet leafhoppers were sent in mailing tubes to Dr. C. O. Townsend, at Washington, D. C. These were placed on beets in isolation cages in the greenhouse, as follows: September 9, two hoppers; September 16, four more hoppers introduced; October 5, four of the eleven plants now have decidedly curled leaves; October 8, seven plants now affected; October 14, nine plants now affected; October 23, ten affected. The beets grown in the open greenhouse beds remained healthy. The beets were quite young; the hoppers were adults.

In still another experiment in the Garland field some adult leafhoppers were placed in a cage with beets not less than three months old, the outer leaves being first stripped off. In this case the disease was longer in manifesting itself, but when it appeared it took the retracted type (figs. 2 and 3).

NYMPH OF BEET LEAFHOPPER MORE HARMFUL THAN THE ADULT.

During the season of 1909 the writer sent other lots of beet leafhoppers to the Office of Sugar-Plant Investigations, at Washington, D. C., and duplicated these experiments, with similar results.[a] In addition, in order to determine the relative effects of the work of nymphs and adults, some of the former were sent from Idaho and caged with twelve seedling beets, the largest of which was not more than 6 inches in leaf spread. Two days after placing these nymphs in the cage the inner leaves of two beets had begun to curl; in three days three and on the eighth day four plants exhibited symptoms of the disease. At the end of sixteen days but four plants showed curl in a cage in which adult hoppers had been imprisoned. On the fifteenth day all of the plants infested by the nymphs had decided curly-top symptoms. Thus it is shown that the nymphs are more virulent than the adults.

In addition to the varied conditions under which these experiments were made, a further set of conditions was introduced in the field. A portion of two rows of sugar beets was covered with a white muslin awning about 15 inches high. The plants under this awning finally thrust their leaves against it and became badly crowded and the soil remained comparatively wet, yet the disease appeared on these plants in about the same ratio as on those in the open field.

HISTORY OF AN OUTBREAK OF CURLY-TOP IN THE EXPERIMENTAL FIELD AT GARLAND, UTAH.

In the experimental field at Garland, Utah, beet seed was sown on April 14 and the few days following. This is some two weeks later than the average in this locality. In a small plat, separated from the main portion of the field by an irrigating ditch running east and west, were sown several strains of seed from beets grown for several generations in very alkaline soil and known, on that account, to be much less vigorous than standard varieties sown in the main portion of the field. These weakly strains occupied all of the small plat except four rows next to the ditch; the four rows comprised strains of about ordinary vigor. On May 4 a small proportion of these weakly seeds had sprouted; the weather continued cold and dry and the seedlings were much retarded. On May 20 a few beet leafhoppers were noted on this plat. By June 13 all of the beets had been thinned. On June 27 eighteen cases of curly-top had developed among the first few rows farthest from the ditch. The beet leafhoppers appear to have started their invasion on that side, but at this date they had become fairly well distributed over the plat.

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[a] Grateful acknowledgment is made of the valuable assistance of Dr. C. O. Townsend and Misses N. A. Brown and C. O. Jamieson in conducting the cage experiments in the greenhouse at Washington, D. C.

On July 9 ninety-five cases of curly-top had developed; these were mostly confined to the part of the plat where the hoppers started. These insects were now rather abundant.

On July 20 the number of plants showing visible signs was the same as on the 9th. Beet leafhoppers had greatly increased in number and were working over the entire plat. On the side nearest the ditch the beets had become well established and of good size. After this date the symptoms developed very rapidly, until on August 10 there were over three hundred cases.

About mid-October, when the beets were dug, only a small percentage of them was free from signs of the disease. Every plant had then been for some time infested by the insects.

Early in August the leafhoppers had spread over the entire field, but, except for a few cases on the edge of the ditch opposite the badly affected plat, practically no plants in the main field exhibited visible symptoms of curly-top. Few leafhoppers could be found in adjacent fields or in the surrounding district, and cases of curly-top were rare in those fields.

The spring weather was unusually backward, with cold, driving, winds through May and the greater part of June. The sky remained overcast and light showers were frequent during the greater part of this period. Until about mid-May only 0.15 inch of rain had fallen, and the ground had become very dry. During the latter part of May 2.69 inches of rain fell; during June, 3.28 inches. This was distributed in frequent showers of little weight. The strong, cold winds soon dried up this moisture. It was not until July was well advanced that really hot weather set in. During that month but 0.34 inch of rain fell.

EARLY SOWING ADVANTAGEOUS IN PREVENTING CURLY-TOP.

Since it appears that very young beets or those in any way retarded or rendered weakly are more likely to succumb to attacks of leafhoppers, and since well-established beets show a decided resistance to these attacks, it is obvious that anything assisting the establishment of a vigorous and early stand of beets will at least render much less severe the effect of an invasion of the beet leafhopper, should that chance to occur. The plants may even entirely fail to develop curly-top symptoms in the latter contingency, though they will inevitably be checked in growth. However, should these insects be very numerous and no means of speedily destroying or driving them away be devised and put in operation, the beets, however large and vigorous, will finally succumb.

A striking instance of the advantage of early planting is the following: Out of 13 acres of a single field, 10 were sown with beet seed between April 10 and 15, the remaining 3 acres not being sown until between May 10 and 20. Beet leafhoppers were abundant there that season. The beets planted in May became so badly affected with curly-top that only 2⅓ tons of beets per acre could be harvested. From the 10 acres planted in April, 16 tons per acre were harvested, few of the plants showing curly-top. The same kind of seed was used and the same cultural methods, irrigation, soil, etc., prevailed over the entire field. The disadvantage of late sowing and poor seed is shown in the case recited as occurring in our small plat.

EXTRACTION OF PLANT JUICES NOT SUFFICIENT TO ACCOUNT FOR THE DISEASE.

That the profound disturbances induced in beets affected with curly-top are not alone due to the extraction of plant juices by leafhoppers seems obvious. A plant like the beet is able to withstand the loss of much more juice than could be extracted by the few leafhoppers that are necessary to induce a bad case of curly-top. The writer saw hundreds of such insects as aphides and red spiders on beet leaves, and the only apparent effect was a local leaf-curl, with discoloration of the parts attacked, but no general and persistent disturbance of the plant as a whole, except when the entire plant was almost covered with these insects, in which case the plant was severely checked and each infested leaf curled. But new growth on such a plant is about normal if the insects are removed. The work of but one leafhopper for a few minutes on a young beet has been shown to be capable of inducing the curly-top symptoms. It therefore seems obvious that some active agent is left in the plant tissues which is capable of initiating profound disturbances.

The writer has observed the symptoms only in growing tissue, and not in mature leaves. Apparently all division is strongly inhibited. This inhibition seems to operate unequally, for, though the growth of the leaf as a whole is checked, the vascular bundles seem to be held back more than the parenchyma between the vascular bundles; the latter soon swells out between the larger veins and produces the "savoyed" effect so frequently noted. To the naked eye no puncture is visible, nor is any local discoloration due to the punctures to be seen by reflected light, as may be seen in the case of other species of hopper—for example, *Eutettix strobi* Fitch, which leaves a crimson-lake spot at the site of every puncture. However, on careful inspection the writer has been able to discern a faint mottling of green with lighter green in the parenchyma of the leaves of young beets by transmitted light when the curly-top symptoms were developing.

In some badly infested beet fields in Idaho the writer has observed leafhoppers feeding on the dock (*Rumex crispus* L.), and the leaves, especially the inner ones, of all such docks were thickly besprinkled with small, wine-colored, circular spots. These spots coalesce when very numerous in a small area, and if they appear on the petioles and veins the discoloration runs some distance along the fibro-vascular bundles. As these leaves get older they become suffused with red in the more spotted area (Pl. I, fig. 2). The same phenomenon has also been noted in mangel-wurzels, or stock beets, infested by the leafhopper.

CONDITIONS FAVORING AN OUTBREAK OF CURLY-TOP.

It has been stated by several observers that dry, hot seasons seem favorable to severe outbreaks of curly-top, either because such conditions are favorable to the activity and multiplication of the leafhoppers or because detrimental to an early and rapid growth of the beets, or a combination of both. It appears that a cold, dry, backward spring, when the seed is slow to germinate and makes a still more tardy growth after germination, is particularly favorable to an outbreak of the disease. While it may prove true that hot, dry weather stimulates the activity of the insects and renders the development of the disease more rapid and severe, it does not yet appear to be established that to keep the soil about the beets in a moist condition will prevent the insects from invading them, from multiplying, or from producing the disease. However, some leafhoppers may be drowned during an irrigation, but the reduction in numbers thus brought about is not considered of much avail.

Our experiments during 1908 and 1909 show that leafhoppers are able to work and induce the disease under conditions extremely varied, both as regards temperature and actual and relative humidity. The crucial point seems to be the number of leafhoppers infesting the beets in relation to the size and vigor of the plants. There is little doubt that the weather has an important bearing on the matter, mainly, it is thought, on account of its influence on the growth and consequent resisting power of the beets; also quite possibly on account of its influence on the leafhoppers. Everything considered, there is good reason to urge early sowing of beets in order to get the plants well established before leafhoppers become numerous.

NATURAL AND ARTIFICIAL BARRIERS TO LEAFHOPPER INVASION.

The writer's observations as to the disposition and manner of beet leafhopper invasions lead him to think that certain natural and artificial barriers check or prevent the invasions. For example, the intervention of a considerable area of land occupied by crops not known to act as food plants to the beet leafhopper probably acts as a more or less effective barrier to an invasion, while land immediately contiguous to a wide stretch of sagebrush country is likely to be invaded any season when the hoppers are abundant. It is thought that the intervention of a mountain or a large body of water will act as a barrier and that the direction of the prevailing winds has an influence. Until late in the season of 1909 the writer had not observed the symptoms of curly-top on other plants than beets, but in northwest Idaho he noted numerous leafhoppers on cabbages growing between two badly infested beet fields. The outer leaves of a few of these cabbages exhibited unmistakable vein symptoms and marginal leaf-curl (Pl. IX, fig. 2).

HOST PLANTS OF EUTETTIX TENELLA.

While there is still some doubt as to the original host plants of *Eutettix tenella* Baker, it is rather probable that the principal ones are greasewood (*Sarcobatus* sp.), sea-blite (*Dondea* sp.), *Atriplex* sp., and Russian thistle (4, 5, 6). The writer has found the insect on *Sarcobatus* sp. and *Atriplex* sp. This insect seems to be native to the southwestern part of the United States (4, 6).

DESCRIPTION OF THE BEET LEAFHOPPER.

The beet leafhopper (*Eutettix tenella*) (Pl. I, fig. 1) is very generally, though erroneously, known in the Western States as the "white fly." The white fly, properly so called (*Aleyrodes citri* R. and H.), is a quite different insect and a common pest of citrus trees. The name "white fly" is doubtless somewhat descriptive of the general appearance of the insect, which is of a light yellowish green tint, looking white at a little distance. In size it is almost exactly one-eighth of an inch long and about one-thirtieth of an inch wide. The nymphs vary in size from but little larger than the egg to almost adult size, according to age; their range of color is almost as great as that of their size. More commonly they are of a creamy white, with irregular areas of brown about the abdomen. These brown areas vary greatly in the amount of pigmentation, so that in general appearance the color ranges through pale cream, buff, light reddish brown, and deeper and deeper browns until some seem almost black; a few have distinctly red markings.[a]

Several other species of leafhopper commonly found on beets closely resemble *Eutettix tenella* in size and color, and few but trained entomologists can readily distinguish between them.

The beet leafhopper is single brooded and begins to deposit its tiny white eggs in the stems and midribs of beet leaves from about the end of June—the time doubtless varying somewhat with the locality and local climatic conditions—until the end of August. Probably the majority of the eggs are deposited by the middle of July. The nymphs begin to appear about the second week in July, and the writer has observed their appearance in considerable numbers in Idaho as late as the end of August. Slit-like scars are produced on the beet stems where the eggs have been deposited; sometimes these ovipository scars are very numerous and conspicuous. The egg stage appears to last about fifteen days, and the young insects reach the adult stage in about twenty days more. These adults hibernate and resume their activity the following spring. In Utah and Idaho they have been seen on weeds in May and on beets near the end of May or early in June. The greater portion of the nymph stage appears to be spent among the inner leaves and petioles of the plant, where the egg is hatched, and as the insect approaches the adult stage it gradually works outward.

The beet leafhopper is an exceedingly active insect; its favorite mode of locomotion is by hops of lightning-like rapidity. The range of its leap seems to be about 18 inches. The adult while on beets uses its wings but little. In common with several closely related species it is a true sucking insect; it is provided with powerful head parts and a stout bill. The latter when not in use is tucked snugly against the under side of the body.

The writer is indebted to Dr. E. D. Ball for much of the data in regard to the life history, habitat, host plants, etc., of the leafhopper, and would refer the reader to the works of this writer for many interesting details and technical descriptions (4, 5, and 6).

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[a] A discussion of this species is given in Bulletin 76, Bureau of Entomology, and a brief practical discussion entitled "Preparations for Winter Fumigation for the Citrus White Fly" in Circular 111 of the same Bureau. The latter may be obtained free on application to the Secretary of Agriculture.

BEET GROWERS SHOULD BE ABLE TO RECOGNIZE THE LEAFHOPPER.

It seems highly desirable that beet growers and field superintendents should be able to recognize the beet leafhopper, so that its earliest appearance may be noted. If successful preventive measures shall be devised, it is very essential to be promptly informed of the first appearance of leafhoppers in considerable numbers, so that such devices may at once be put in operation. It has not been shown that any other species of leafhopper is able to induce the curly-top symptoms, though both Doctor Ball and the writer have independently experimented with other species commonly found on beets.

SERIOUS NATURE OF CURLY-TOP.

The serious nature of curly-top may be understood when it is known that in some localities practically the entire sugar-beet crop has been destroyed. The writer has seen fields of beets completely denuded by it. Furthermore, beets that do produce a root of fair size because attacked comparatively late in the season possess a high percentage of impurities and are on that account not so desirable to the sugar companies.

It may be said that beets once affected with curly-top never recover. Even when the affected foliage is cut back repeatedly at intervals of several weeks, the new growth exhibits unabated symptoms (29).

A CONSIDERATION OF CURLY-TOP IN SEED BEETS.

It has been observed by those who have raised beet seed in the regions subject to the scourge of curly-top that a variable percentage of seed beets will manifest symptoms of the disease with the first shoots to appear in the early spring. This has been noted by several members of the Office of Sugar-Plant Investigations and by Doctor Ball (6).

The following specific cases are good illustrations: In addition to the cases of curly-top observed in June, 1907, among sugar beets (see p. 13), the writer noted a fair percentage of seed beets thus affected, but at that time little special attention was given the latter. It was merely assumed that they might have contracted the disease at the same time and in the same manner as the sugar beets, however that might have been. No sugar beets exhibiting visible signs of the trouble were selected for siloing in the fall of 1907. Among those selected for use as seed beets were some of the pedigree and garden beets referred to as showing a large percentage of curly-top, together with a considerable number of apparently healthy beets of standard varieties.

The silos were opened April 10, 1908, and the beets were planted April 10, 11, and 13 in the experimental field at Garland, Utah. Within ten days they began to sprout. In the meantime the weather was very severe, with great extremes of temperature. On May 24 most of these beets had sprouted, and many of the pedigree beets showed suspicious signs of curly-top. The closest scrutiny failed to reveal the presence of leafhoppers at this time. On May 14 a canvass of the entire plat of seed beets showed the trouble to be more widespread than at first supposed, though even at this date no leafhoppers had been seen. By May 20 one portion of the pedigree beets showed signs of the disease to the extent of 48.67 per cent, and another portion 29.36 per cent, as against 3.87 per cent among the standard varieties. At this time a few beet leafhoppers had appeared on the small plat that later became so badly affected. On June 8 the percentage of plants visibly affected was 52.21, 58.54, and 17.19, respectively. The writer could not assign the cause of the outbreak among the seed beets to the few leafhoppers then in evidence. Indeed, the first cases of curly-top did not appear among seedling sugar beets in the plat mentioned until about three weeks later, when the insects had become much more numerous.

The experiments hitherto described in connection with the work of the beet leafhopper on sugar beets, whereby this insect was shown to be the primary causative agent of curly-top, together with the observations just set forth, led to the conclusion that the disease may be initiated in the seed beets by the hopper during the season preceding their use for seed production. In order to determine this point conclusively it was arranged to take advantage of the outbreak of curly-top in the small plat during 1908. To this end there were selected from this plat about one hundred beets of good size and shape that at the end of the season exhibited no visible signs of the disease; also, one hundred similar beets showing well-developed symptoms of the trouble were selected from the same plat. All were carefully siloed for planting in the spring of 1909. Many beets were also siloed from the major portion of the field, where but few cases of the trouble had appeared, though these latter plants had been infested by leafhoppers during the later part of the season.

Very early in April, 1909, these beets were planted out in the usual manner. From the moment of planting, close watch was kept for leafhoppers of any species. Almost with the first appearance of the shoots of the seed beets from the affected plat of last season, whether or not the beets had then exhibited symptoms of curly-top, the characteristic curl and vein symptoms appeared. On May 24 all those beets showing curly-top when harvested at the end of the preceding season had again developed the symptoms. Of those showing no symptoms when harvested, 83 per cent were affected on the same date. Later in the season but 2 per cent of this latter batch was free from visible symptoms of the disease, and even the 2 per cent was checked in growth. Of the large number of beets siloed from the major portion of the field, where practically no cases of the disease had appeared during the preceding season and which were planted out at the same time in the spring for seed production, about 10 per cent had developed curly-top on May 24. It will be remembered that no leafhoppers appeared until May 20, and then but few.

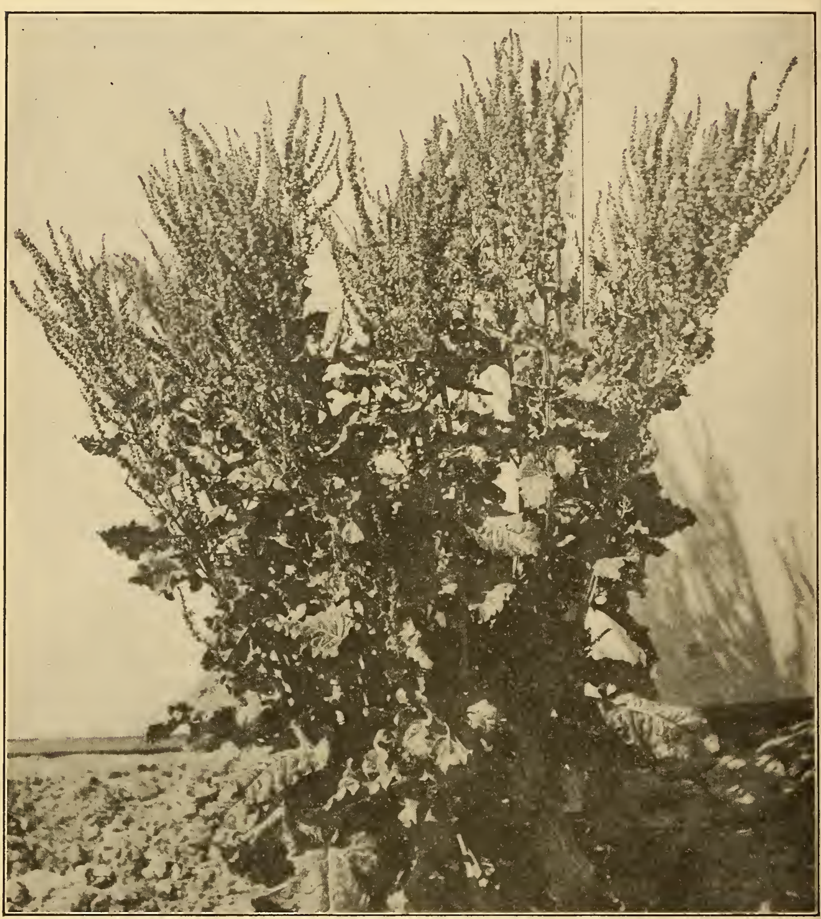

FIG. 7.—Mature healthy seed beet. (For comparison with seed beets affected with curly-top.)

The same spring some of the standard varieties of seed beets (see fig. 7) were planted at Central Farm, about 6 miles from our experimental field at Garland; other lots were planted at North Farm, about 1½ miles away; at Corinne, about 16 miles away, and at Lehi, about 100 miles distant. At these places it was difficult to find a single beet leafhopper during the entire season. Nevertheless, a like percentage of curly-top appeared among the beets planted at each place. Furthermore, there had been planted at Corinne some of the apparently healthy beets from the badly affected plat at Garland. All these manifested the characteristic signs of the disease very early. Numerous seed beets were sent from Fairfield, Wash., and planted at Central Farm in the plat with those just referred to. Among these no curly-top appeared. No beet leafhoppers could be discovered at Fairfield the preceding season.

During the same spring some beets were sent from Garland to Compton, Cal., to be planted there as seed beets. Most of these developed curly-top, although no leafhoppers could be found at Compton. None of the factory beets or seed beets grown there became affected.

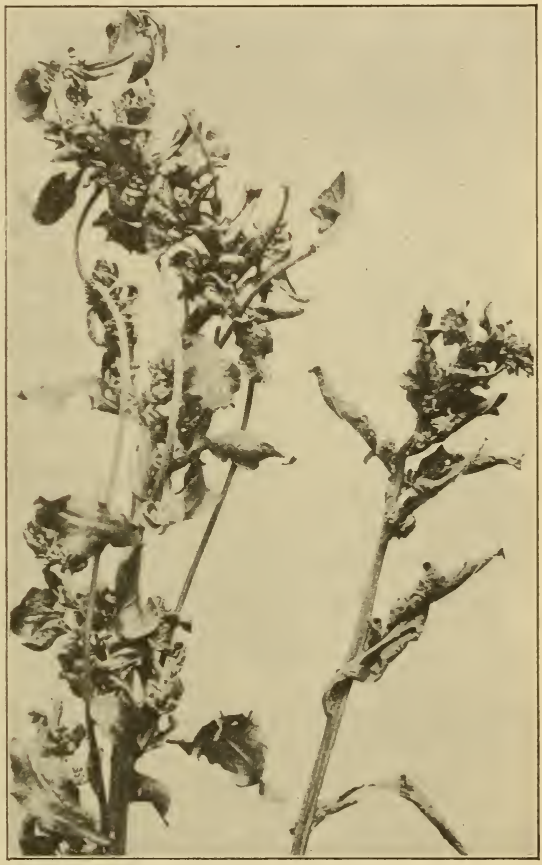

FIG. 8.—Sugar-beet seed stems showing curly-top symptoms. These stems had been denuded of all but single-germ seeds and a few bracts; the new growth alone exhibited curly-top symptoms.

These results go to show that the changes set up by beet leafhoppers are profound and persistent and that while a beet may have been resistant during its first season to the extent of growing to about normal size without exhibiting signs of the disease, some reaction has been initiated that will show itself in the manner characteristic of curly-top the following spring if the beet is planted for seed purposes.

Of seed beets the writer could never observe that plants as a whole ever succumb to the attacks of the leafhoppers during the season they are planted as seed beets. They are too vigorous and resistant, and nearly all the leaves are full grown before beet leafhoppers appear in number. However, individual shoots and racemes put forth late in the season may manifest the symptoms if attacked by leafhoppers (fig. 8). Then, too, the entire aftergrowth, which generally develops late in the summer, after the seed has been harvested, may exhibit pronounced signs of the disease. This actually occurred on the plat at Garland after the seed harvest of 1908, when the aftergrowth of nearly every seed beet became thus affected. This aftergrowth consisted of actively growing and immature leaves in which cell division was taking place.

The symptoms are generally more diverse in seed beets. Apparently the element of greater resistance on account of greater size and vigor is a factor tending to the production of symptoms not commonly noted in young sugar beets. However, these additional, and among sugar beets less usual, symptoms may be seen in sugar beets when quite large plants are attacked by so many leafhoppers that even they finally succumb. These symptoms are those mentioned as the retracted type.

The writer has been able to produce the retracted curl under test conditions by imprisoning a gradually increasing number of leafhoppers with beets that would ordinarily fail to develop the symptoms on account of their size when attacked by the insects (see figs. 2 and 3).

SEVERAL TYPES OF LEAF-CURL ON SEED AND SUGAR BEETS.

As a result of observations on the development of the disease in seed beets the writer has been able to note several types of symptoms on them, as follows:

(1) The type most commonly noted on sugar beets and hitherto regarded as the characteristic appearance of beets affected with curly-top, viz, with leaves strongly curled inward from the entire margin toward the midrib; strongly knotted veins; thickened parenchyma, which in advanced stages is quite brittle, though tough and leathery in appearance; very dark and dull green foliage with outer whorls sear and dead; pronounced inhibition of growth; early appearance of feeble seed stem, which sometimes does and sometimes does not mature seed. (See Pl. I, fig. 1; Pl. II, fig. 1; Pl. IV, fig. 1; Pl. VI, fig. 1; and Pl. IX, fig. 1.)

(2) The type with short, ovate, retracted leaves and short, bowed petioles: tissue between larger veins puffed out as though the parenchyma had outgrown the fibro-vascular tissue; veins generally rather less knotted than in the preceding type; generally the early appearance of abortive seed stems; almost entire inhibition of growth after first month. This type is perhaps the most abundant one among seed beets and is found also on sugar beets that succumb late in the season after attaining a considerable size. (See Pl. III, fig. 1, and Pl. V, fig. 1.)

(3) The type with long, narrow, sinuous, thick, leathery-looking leaves; without marginal curl or vein symptoms; no seed stems; almost entire inhibition of growth after first month or six weeks; dull, dark-green foliage, inclined to russet. (See Pl. IV, fig. 2.) Noted only on seed beets.

(4) The type with small rosettes of leaves similar to those of the second type mentioned, but much smaller; very early cessation of growth; no seed stems; very feeble vitality, yet root apparently quite solid and crisp. (See Pl. V, fig. 2, *B*.)

(5) The type with root apparently as sound and crisp when planted as the most healthy beet, yet making no growth at all.

(6) The type with part of shoots affected with marginal curl, inward; growth not otherwise seriously affected; part of shoots apparently normal.

(7) The type with no visible symptoms of the disease, but general growth checked. (See Pl. VI, fig. 1.)

(8) Combinations of any of the foregoing. (See Pl. V, fig. 2, *A*.)

AFFECTED SEED BEETS ALMOST NONPRODUCTIVE.

The serious nature of curly-top is heightened by the fact that few seed beets affected by it produce seed. Of those possessing sufficient vitality to produce seed stems, many dry up and die before maturity; the very few that produce seed are so puny and stunted as to produce but a small fraction of a normal yield. Thus, it will be seen that, while this species of leafhopper is a serious menace to the sugar-beet crop, it is doubly so when beets are raised for seed. The beets may be quite satisfactory for the manufacture of sugar and appear normal and healthy when harvested, yet have stored within them an active agent that may cut down the seed crop from a few per cent to entire loss.

PERCENTAGE OF LOSS OF SEED BEETS.

When put in plain figures this loss is very striking. To revert to the experiment just mentioned, those plants showing no curly-top when siloed produced an average of only 13.82 grams of seed; those exhibiting signs of the disease when harvested produced but 13.25 grams per plant. The average for the healthy beets was about 375 grams, or about twenty-eight times as much as the yield of affected plants. (See fig. 9.)

During 1905 an important sugar-beet district was afflicted by an invasion of *Eutettix tenella* which resulted in great loss. The sugar company, however, selected and siloed enough apparently healthy beets to plant 4½ acres in the spring of 1906 for seed production. Of these, 1½ acres were entirely unproductive; only 1,200 pounds of seed were obtained from the other 3 acres, or 400 pounds to the acre, or 36.3 grams per plant. In 1906, when the sugar-beet crop was good in the same district and few leafhoppers appeared, enough beets were selected to plant 8.29 acres. These seed beets yielded 16,800 pounds of seed, or 2,038.6 pounds to the acre, or about 177.6 grams per plant. The difference here shown is not so great as in the experiment conducted by the writer because not all of the beets siloed by the sugar company could have been as severely attacked during the preceding season; then, too, the plants used by the writer were set much farther apart than those of the sugar company, thus encouraging a larger yield among the healthy beets.

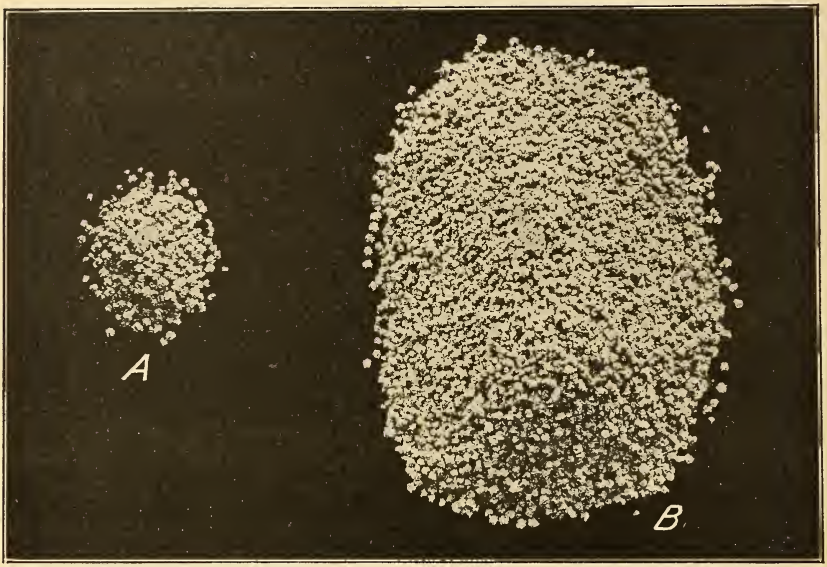

Fig. 9.—Average seed yield of healthy and curly-top sugar beets: (*A*) Average amount from diseased beets, 13.25 grams; (*B*) average from healthy seed beets, 375 grams.

SEVERE OUTBREAKS NOT FREQUENT IN A LOCALITY.

A notable feature of curly-top is that, so far as has been recorded, there never has been a serious outbreak two seasons in succession in any locality. Therefore, the farmer may be encouraged to continue the culture of sugar beets in spite of the heavy loss consequent on a single attack. This opportunity is taken, however, to utter a note of warning to seed producers to the effect that it will be unprofitable to silo sugar beets harvested from an area badly affected with curly-top, even though no beets exhibiting the characteristic symptoms are selected for siloing. Furthermore, should the beet leafhoppers be numerous without producing more than a sprinkling of plants showing visible signs of the disease, a more or less considerable percentage of loss may be expected through the development of the disease in seed beets the following season. The probable amount of loss will obviously depend on the number of leafhoppers present during the preceding season, together with the general vigor of the plants at that time and the length of time the leafhoppers had been at work on the beets.

PROGENY OF THE DISEASED SEED BEETS HEALTHY.

Another strange feature of curly-top is that the seed from an affected seed beet will produce healthy sugar beets, which in turn afford vigorous and healthy seed beets unless in the mean time they are attacked by more leafhoppers. Thus it appears that seed from affected beets need not be discarded on account of the disease.

GENERAL CHARACTER OF CURLY-TOP.

It would appear from these observations and experiments that the curly-top of beets should be included in the group of plant disturbances known as "stigmonoses," as described by Dr. A. F. Woods in connection with the effects of aphides, thrips, and other sucking insects on the carnation (32, 33, 34, 35, 37), by Dr. N. A. Cobb as occurring on apples, pears, etc. (10), and by Moulton as occurring on the pear (21). Curly-top resembles these stigmonoses in that the disturbances are primarily set up by the punctures of sucking insects—the beet leafhoppers. In certain varieties of beets and in docks punctured by the beet leafhopper, discoloration and spotting of the leaves follow the punctures of these insects, and in young sugar beets a faint mottling of the attacked leaves may be noted by transmitted light (see p. 10) ; leaf distortions, though differing in character and extent, are common to both. In the case of stigmonose, Woods has shown that when the abnormal changes due to aphis punctures " have once been started in a plant the ill effects continue long after the initial cause has disappeared. If the insects are killed or kept off such a plant the new growth will be free from spots and therefore apparently healthy. It is, however, poor in reserve albumin and has an excessive amount of oxidizing enzyms * * * and is therefore in fact diseased. This malnutrition becomes gradually cumulative from generation to generation of cuttings, and so far as our investigations have gone, can not be cured." In this respect the behavior of curly-top beets is almost identical, the most noteworthy difference being the persistence of the visible symptoms in all new growth of curly-top beets, even after repeated cuttings back of the foliage at intervals of several weeks.

In the cases described by Woods and others the visible effects of the insect punctures are confined to the leaf, or even the portion of the leaf, attacked, whereas, as just stated, the disturbance induced in the curly-top beet affects the whole plant in such a manner that all of the growing foliage shows visible symptoms of the disturbance.

While curly-top is initiated in the same manner as stigmonose and so far as can be discovered (29) can not be attributed to bacteria or fungi, the physiological disturbances seem to bear a close resemblance also to those described by Woods and others (7, 15, 18, 19, 20, 23, 24, 25, 34) as mosaic. In the case of curly-top it is true that the rather conspicuous leaf mottling noted in the mosaic disease is absent, except for the faint mottling already referred to as occurring in leaves of young beets affected by curly-top and visible only by transmitted light. On the other hand, the general nutritional disturbances and the unbalancing of normal enzym activities described by Woods (33) seem to be duplicated in curly-top beets; in the latter, too, there is a similar persistence of visible symptoms. Still another feature is common to both the mosaic disease and curly-top, viz, under both conditions an affected plant will sometimes yield seed, and in each case that seed is capable of producing normal, healthy plants.

The writer has not yet secured conclusive evidence that these symptoms can be induced in beets by the methods practiced by Woods (34) in the case of the mosaic disease. Indeed, it would appear to him difficult to do so, for the reason that the beet root contains so large a reserve of nutrients. Townsend's experiments (29) and some conducted by the writer seem to negative the idea, but further investigations along this line are necessary. However, the writer is of the opinion that there is a striking resemblance in the general behavior of curly-top beets to that of those suffering from the mosaic disease.

This would indicate that curly-top is the most conspicuous and destructive form of stigmonose and, at the same time, one of the most interesting to the pathologist and physiologist on account of the profound disturbances set up, as well as from its apparent relationship to the mosaic disease. Apart from curly-top the writer has noted stigmonoses of the sugar beet which are identical with those described by Woods, Cobb, and Moulton, as well as with others caused by different species of leafhoppers.

SUMMARY.

The curly-top of beets is related causatively to stigmonose; pathologically and physiologically to both stigmonose and the mosaic disease. It manifests itself through numerous external and internal symptoms of diverse character.

The aggregate of these symptoms presents an appearance characteristic of this disease, though taken individually all except the vein symptoms have been noted under other conditions.

Two distinct types of curl are manifested in this disease—the inward and the outward, or retracted.

The symptoms are essentially alike in factory and seed beets. Among seed beets there is a larger proportion of the retracted type.

The beet leafhopper (*Eutettix tenella* Baker) is the primary cause of the trouble; no outbreaks are known to have occurred outside of the native habitat of this insect, viz, the Southwestern States, generally in the vicinity of what is known as "sagebrush country." The plants named as the probable host plants of the beet leafhopper are found where outbreaks of curly-top have occurred. The insect probably migrates from those plants to beets.

One leafhopper is capable of initiating the disturbances in a young beet, and the effect of numerous hoppers on seedlings may be so severe as to kill them in a few days, before the visible symptoms have had time to develop. The younger the beet the more sensitive is it to leafhopper work.

The nymphs of *Eutettix tenella* produce the symptoms of curly-top much more rapidly than do the adult insects.

No other insect and no other species of leafhopper is known to induce the disease herein described.

Though vigorous beets of four months growth or older will offer considerable resistance, any beet will succumb if attacked by numerous beet leafhoppers. Neither is any variety of beet immune.

The symptoms appear only on immature leaves where cell division is still active—never on full-grown leaves. They appear first on the inner leaves just as the latter unfold.

It is considered advisable to plant as early as practicable after danger of late frosts is over, even to take some risks of late frost, in order to get the beets well established and vigorous before leafhoppers are likely to be numerous.

The disease can not be due to loss of plant juices extracted by leafhoppers, but rather to the introduction by those insects of an active agent.

Few or no beets that develop curly-top symptoms ever recover.

Beets may fail to show symptoms of curly-top to the end of the season if attacked by leafhoppers after they have attained considerable size and vigor. Yet the trouble is initiated and transmitted to the root, only to develop with full virulence in the first shoots the following spring if they be planted out for seed production.

The active agent is therefore persistent and sets up disturbances throughout the whole plant.

It is risky to select for seed purposes any beets from fields badly infested with beet leafhoppers, even though no large number of cases of curly-top appear.

It is useless to make selections for seed from fields badly affected with curly-top.

The inward type of curl is generally produced on young beets. The retracted type appears on seed beets and on sugar beets that had attained considerable size and vigor before the symptoms developed.

Until recently curly-top symptoms had been noted on no other plants than beets, but the writer noted the symptoms on cabbage in 1909.

The punctures of the beet leafhopper produce wine-colored stains on the leaves of dock (*Rumex crispus* L.) and on stock beets, but no such discoloration has been observed on sugar beets.

Anything tending to retard or weaken beets renders them less resistant to leafhopper attacks.

The leafhoppers can induce the symptoms of curly-top under extremely varied conditions of moisture, temperature, and atmospheric pressure.

Weather, soil, etc., may influence the severity of the disease indirectly by modifying the vigor of the beets; possibly, also, the leafhoppers are influenced favorably or otherwise by varying weather conditions.

If seed beets are really healthy when planted—that is, if they have not been subjected to the attacks of leafhoppers during their first season's growth—there is little chance that they will succumb to leafhopper attack during their season as seed beets. An attack involving the whole seed beet is perhaps without exception the result of attacks during the preceding season, though no symptoms may then have appeared. Portions of the later shoots and the aftergrowth of leaves following the seed harvest have frequently been known to develop the symptoms.

Few affected seed beets are capable of producing seed, and then only in very small quantity. The seed yielded by affected seed beets will, however, produce healthy sugar beets, which, in turn, unless in the mean time attacked by more leafhoppers, are capable of becoming good seed beets.

It has not been found possible to communicate the disease from an affected plant to a healthy one.

CONCLUSION.

In cooperation with the Bureau of Entomology, the writer has already carried on some spray experiments in the hope of devising a method of holding the destructive beet leafhoppers in check. It was found that, if it can be thoroughly applied to the insects, a strong kerosene and whaleoil-soap emulsion will kill them. However, the time is so short when the spray might efficaciously be applied that it is not yet certain that spraying will be practicable. Then, too, it is not easy to apply a spray to the beet leafhopper, because its wings thoroughly protect its body and thus prevent the emulsion becoming effective.

Possibly some form of "hopper-dozer" used at the right time will prove more serviceable. More experimental work is needed along these lines.

At the suggestion of the Bureau of Entomology, the following recommendations, found in Bulletin 66, Part IV, of that Bureau, pages 47–48, are quoted:

> More should be known about the places of hibernation and early spring history of this insect. It could not be found in the rubbish around the fields in early spring, and only a few specimens were found in waste places up to the time they appeared on the beets. When once the place where the greater number of them pass the winter is discovered, it may be possible to destroy them there or on their spring food plants before they migrate to the beets. After they have appeared on the beets it will be necessary to be very prompt in the matter of remedies if the injury is to be prevented. A thorough spraying with kerosene emulsion at a strength of 1 part of the stock solution[a] to 5 parts of water would destroy most of the insects that it hit, and by using a drag in front of the nozzles to turn the leaves over and cause the insects to jump, most of them could be reached. Where the insects were coming in in numbers this spray would need to be followed by a second one ten days later.
>
> Several mechanical devices have been used to catch different leafhoppers, and no doubt several of these could be used against this insect with advantage. The tar pan, or "hopper-dozer," drawn over the beets two or three times in

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[a] For directions regarding the preparation and use of kerosene emulsion see Farmers' Bulletin 127, U. S. Dept. of Agriculture, pp. 20–21, and Circular 80, Bureau of Entomology.

the first few weeks would capture a large number of them. The females, before the eggs are laid, are quite heavy and do not jump or fly as readily as the males and would be easily caught. A modified form of this machine, consisting of a couple of tarred wings to be drawn along on each side of a row of beets, while a drag agitated the tops and caused the insects to fly, would probably capture more than the simpler tar pan.

If the insects appeared while the beets were quite small, they could be largely destroyed by rolling when the weather was cold or damp and the insects sluggish.

A number of preventive measures may be used to assist the beets in withstanding the attack of the leafhoppers. In some sections early planting will produce beets large enough to shade the ground by the time the beet leafhoppers appear, and thus reduce the temperature below the danger line. In a few places, like the Grand Junction district in Colorado and Sevier County in Utah, early planting alone would not avail, as the insects appear soon after the earliest beets come through the ground. For such sections early and frequent irrigations would assist in keeping the ground cool until the beets grew large enough to shade it and thus take care of themselves.

All preventive measures will depend for success upon some method of controlling the temperature in the field so that the ground may not be hot and dry at the time the leafhoppers appear.

RECOMMENDATIONS.

Undoubtedly some of the remedies advised against the hop flea-beetle, an entirely different insect and one which also affects sugar beets, in Bulletin 66, Part VI, of the Bureau of Entomology, pages 83–91, and a supplementary article, Bulletin 82, Part III, on the same species, will be found useful. Particular attention is called to the latter publication, by Mr. W. B. Parker, collaborator of the Bureau of Entomology, as the experiments have been very carefully carried out with the hop flea-beetle, which from its habit of flying quickly and hopping resembles leafhoppers, in that the beetles can be reached in somewhat the same way.

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Probably the first account of the disease now known as stigmonose.

2. ——— and **Bolley, H. L.** Bulletin 59, Purdue University Agricultural Experiment Station, vol. 7, 1896.

Stigmonose of carnations is described under the name "bacteriosis." The disease is regarded as mainly affecting the leaves.

3. ——— and **Golden, Katherine E.** A disease of the sugar beet root. Proceedings, Indiana Academy of Science, 1891, p. 92.

These writers verified an appearance of bacteria in the roots of beets affected with a leaf-curl, producing a "savoyed" appearance in the leaves. They were unable to reproduce the symptoms by inoculating with pure cultures of the bacterium.

4. **Ball, E. D.** The genus Eutettix. Proceedings, Davenport Academy of Sciences, vol. 12.

Ball here describes various species of leafhoppers, including the beet leafhopper (*Eutettix tenella* Baker), and from the observed appearance of the latter at the time of outbreaks of curly-top of beets is of the opinion that this insect is the cause of the disease.

5. ——— The beet leafhopper. Sixteenth Annual Report, Utah Agricultural Experiment Station, June, 1905, p. 16.

Ball here holds that the leafhopper (*Eutettix tenella*) is the cause of curly-top.

6. ——— The leafhoppers of the sugar beet, and their relation to the curly-leaf condition. Bulletin 66, pt. 4, Bureau of Entomology, U. S. Dept. of Agriculture. Jan. 27, 1909.

Ball here describes the beet leafhopper and closely related species and concludes that *Eutettix tenella* is the cause of curly-top. Not experimentally demonstrated.

7. **Beijerinck, M. W.** Verhandelingen der Kroninklijke, Akademie van Wetenschappen te Amsterdam. 1898.

Beijerinck proved the absence of bacteria in cases of the mosaic disease and found that only dividing cells (meristemic) can become diseased. He defines a milder form of the disease as a suffering of the chlorophyll bodies; later on a general disease of entire plasmic contents.

8. **Büsgen, M.** Der Honigtau. Biologische Studien an Pflanzen und Pflanzenlausen. Bes. Abdr., a. d. Jena Zeitschrift für Naturwissenschaft, vol. 25, N. F., vol. 18.

Büsgen pointed out that the puncturing apparatus of the aphis does not lacerate the plant cells, but passes between them.

9. **Busse, Walter.** Bakteriologische Studien über die "Gummosis" der Zuckerruben. Zeitschrift für Pflanzenkrankheiten, vol. 7, 1897, pp. 65–77, 149–155.

A disease bearing resemblance to curly-top is here referred to as "gummosis."

10. Cobb, N. A. Letters on the diseases of plants, 2d series. Miscellaneous publication No. 666, Dept. of Agriculture, Sydney, New South Wales, 1904, pp. 38–50.

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A disease of beets in which a leaf-curl is conspicuous is described, and the writer concludes that it is caused by bacteria in the root. This is not clearly established.

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Czapek demonstrated a relation of oxidizing enzyms to geotropic curvature in root of several genera of plants, which suggests the possibility that there may be such a relation between oxidizing and reducing substances in plants sensitive to certain parasites.

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This paper describes the isolation of bacteria from roots of beets affected by a leaf-curl.

14. Huston, H. A. Sugar beets. Bulletin 39, part 2, Purdue University Agricultural Experiment Station, 1892, p. 49.

The abnormal appearance of certain beets prepared for analysis is described.

15. Koning, C. Zeitschrift für Pflanzenkrankheiten, vol. IX, 2, pp. 65–80.

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17. Lapham, M. H., and Heileman, W. H. Field operations of the Bureau of Soils, U. S. Dept. of Agriculture; soil survey of the Lower Salinas Valley, California, 1901, p. 506.

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22. RAVAZ, L. Progrès agricole et viticole, nos. 21 and 24. 1900.

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The appearance of beets affected with curly-top is here described.

25. STURGIS, WILLIAM C. Twenty-Second Annual Report, Connecticut Agricultural Experiment Station (1898), pp. 252, 253, 1899.

A critical review of the work done on the mosaic disease to that time is presented, together with the writer's own observations and conclusions.

26. ——— Twenty-Third Annual Report, Connecticut Agricultural Experiment Station (1899), vol. 3, 1900, p. 253.

The writer here points out that close, clayey soils are favorable to the development of mosaic disease because unfavorable to the even growth of plants.

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The writer here reviews the work on the nature and cause of curly-top of beets, recites the various theories advanced, and shows that none of them to that date had accounted for it.

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Woods describes the mosaic disease of tobacco and shows it to be probable that there is a disturbance of nutrition due to a lack of balance in the relative amounts or activity of enzymes, that the oxidizing enzymes seem to be abnormally active in the diseased cells, and that the mode of operation is to weaken or retard the action of the diastase. The action of the oxidizing enzymes upon the diastase, therefore, retards the production of sugar, and consequently of proteids and reserve nitrogen in general. The conclusion is reached that the disease can not be due to parasites, but must be attributed to a disturbance of the normal physiological activity of the cells in question. Whatever causes the reduction of available nitrogenous reserve food, especially soluble nitrogen, below the requirements of dividing cells may cause this disease in the tissues of certain plants.

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37. ——— Carnations in health and disease. Florists' Exchange, vol. 13, 1901, pp. 188–189, and American Florist, vol. 16, no. 664, 1901, pp. 990.

This paper contains substantially the matter presented in "Stigmonose, a Disease of Carnations and Other Pinks."

PLATES.

DESCRIPTION OF PLATES.

Plate I. Work of the beet leafhopper (*Eutettix tenella* Baker). Fig. 1.—Beet leaves affected by curly-top; also a beet leafhopper. (*A*) A beet leaf with inward curl and pronounced vein symptoms; (*B*, *C*) two small beet leaves with retracted type of curl; (*D*) beet leafhopper, adult. Fig. 2.—Dock leaf (*Rumex crispus* L.) spotted by punctures of beet leafhopper. These spots are of dark crimson-lake, punctate but gradually becoming diffuse; on the fibro-vascular bundles they become lanceolate. Natural size.

Plate II. Work of beet leafhopper on seedling beets. Fig. 1.—Healthy and curly-top sugar-beet seedlings and leaves. (*A*) Healthy seedling; (*B*) curly-top seedling with well-developed hairy-root, bowed petioles, vein symptoms, and leaf curl; (*C*) front view of an inner leaf from plant *B*, showing marginal curl; (*D*) dorsal view of similar leaf, showing vein symptoms. Fig. 2.—Healthy and curly-top sugar beets of medium size. (*A*) Curly-top beet with hairy-root, tough and fibrous root, wide crown with many imperfect leaves sprouting therefrom; (*B*) beet in perfect health.

Plate III. Effects of leafhopper attacks. Fig. 1.—Large sugar beet affected late in the season by curly-top. The retracted type of curl appears to be produced by leafhoppers when they attack a large beet in considerable numbers. Fig. 2.—Sections of healthy and curly-top sugar beets, showing the discoloration of fibro-vascular bundles. (*A*) Longitudinal and (*B*) oblique sections of a healthy sugar beet, showing the very light, delicately traced fibro-vascular bundles of the root. (*C*, *D*) Similar sections of a curly-top beet, showing the dark areas, dark fibro-vascular bundles, and blackened area with incipient cavity near crown; (*E*, *F*) similar sections of curly-top beet, showing more pronounced blackening of bundles and a cavity with black walls near crown.

Plate IV. Seed beets affected by curly-top. Fig. 1.—Seed beet exhibiting inward type of curl. Fig. 2.—Seed beet with long, sinuous type of leaves due to curly-top; this type never produces a seed stem.

Plate V. Seed beets affected by curly-top. Fig. 1.—Seed beet showing retracted type of curl. The greater portion of seed beets thus affected have this type of leaf-curl. Fig. 2.—(*A*) Seed beet showing both inward and retracted types of leaf-curl; (*B*) seed beet with rosette of severely retracted leaves and no seed stem. With this type of curl no seed stem ever develops.

Plate VI. Seed stems of curly-top beets. Fig. 1.—Curly-top seed beets maturing seed. Fig. 2.—Seed beet slightly affected by curly-top; very slight symptoms of the disease are apparent; the trouble is shown principally in the checking of growth. Compare with Plate VII, which shows a healthy seed beet of the same age photographed to the same scale.

Plate VII. Healthy seed beet of same age as that shown in Plate VI, figure 2.

Plate VIII. Root conditions of seed beets affected with curly-top. Fig. 1.—Seed beet badly affected by curly-top and root almost destroyed by rot. (Probably *Phoma betae* or Rhizoctonia.) Rot not caused by the curly-top. Fig. 2.—Seed beet with sound root, though badly affected with curly-top. This root was as crisp and sound as when siloed more than seven months earlier.

Plate IX. Fig. 1.—Two young sugar beets showing curly-top symptoms under test conditions with leafhoppers. These plants were placed under ½-gallon Mason jars with two to four leafhoppers, and the disease developed as the result of their attacks. Mason jars shown in the background over other beets. Fig. 2.—Portion of cabbage leaf showing curly-top symptoms after leafhopper attacks; no visible spotting of leaves. These cabbages grew in a small plat between two badly leafhopper-infested fields; many leafhoppers were noted feeding on the outer leaves of the cabbages.

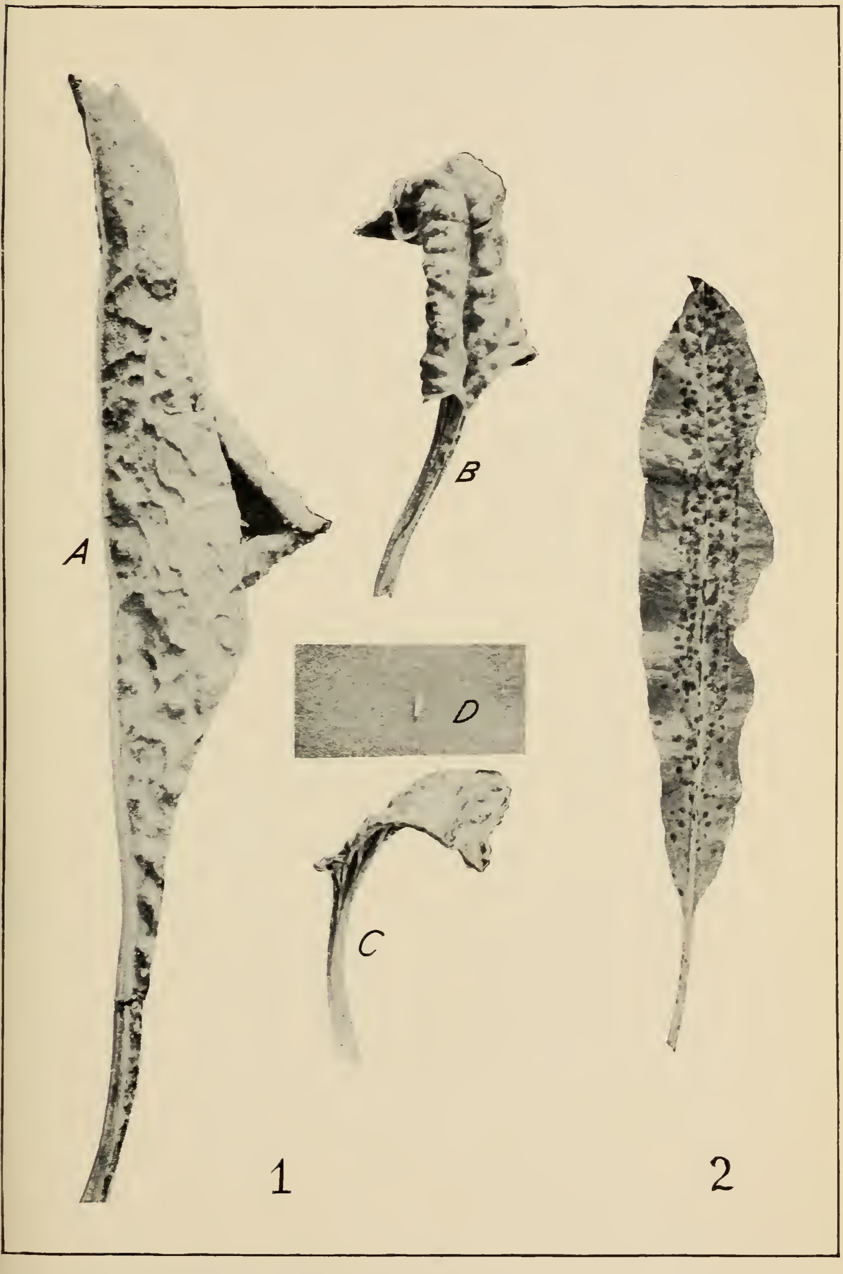


FIG. 1.—BEET LEAVES AFFECTED BY CURLY-TOP (*A*, *B*, *C*); ALSO A BEET LEAFHOPPER (*D*). FIG. 2.—DOCK LEAF SPOTTED BY PUNCTURES OF BEET LEAFHOPPER.

(Natural size.)

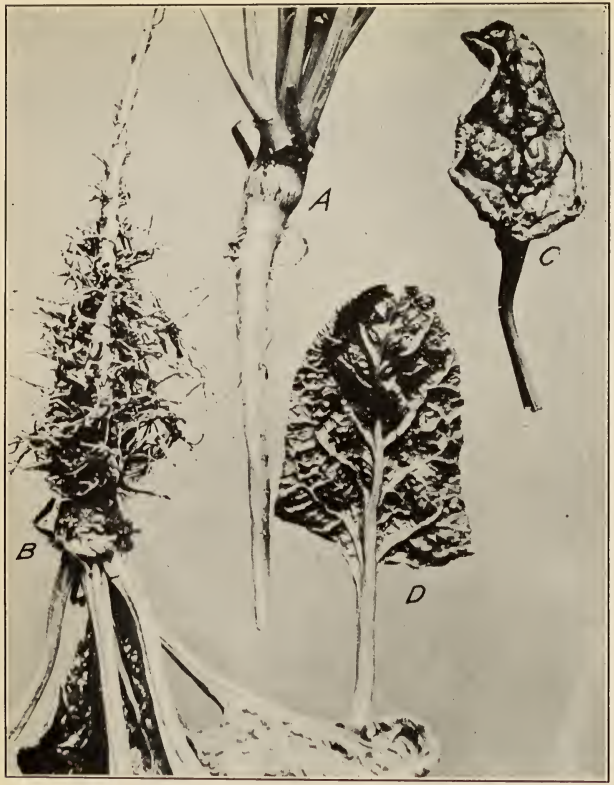


FIG. 1.—SUGAR-BEET SEEDLINGS AND LEAVES IN A HEALTHY CONDITION AND OTHERS AFFECTED BY CURLY-TOP: *A*, HEALTHY SEEDLING; *B*, SEEDLING AFFECTED BY CURLY-TOP; *C*, FACE OF BADLY AFFECTED LEAF; *D*, DORSUM OF SIMILAR LEAF.

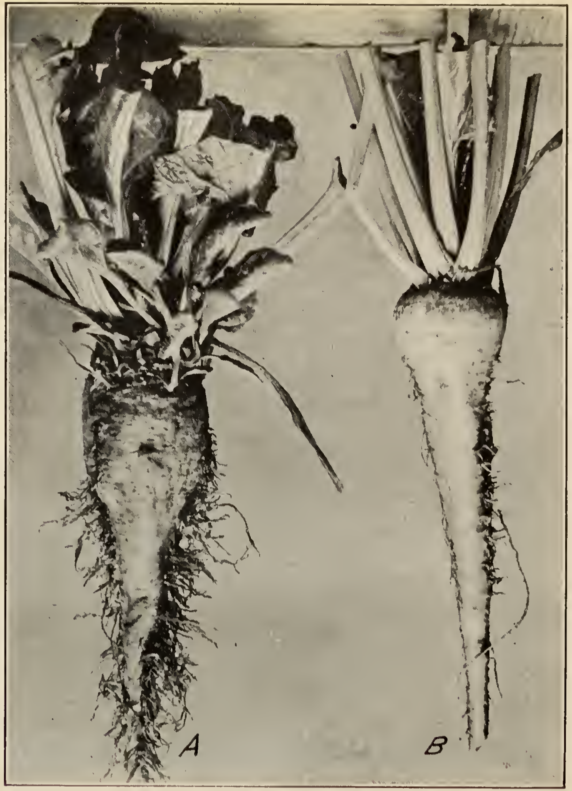


FIG. 2.—HEALTHY AND CURLY-TOP SUGAR BEETS OF MEDIUM SIZE: *A*, CURLY-TOP BEET; *B*, HEALTHY BEET.

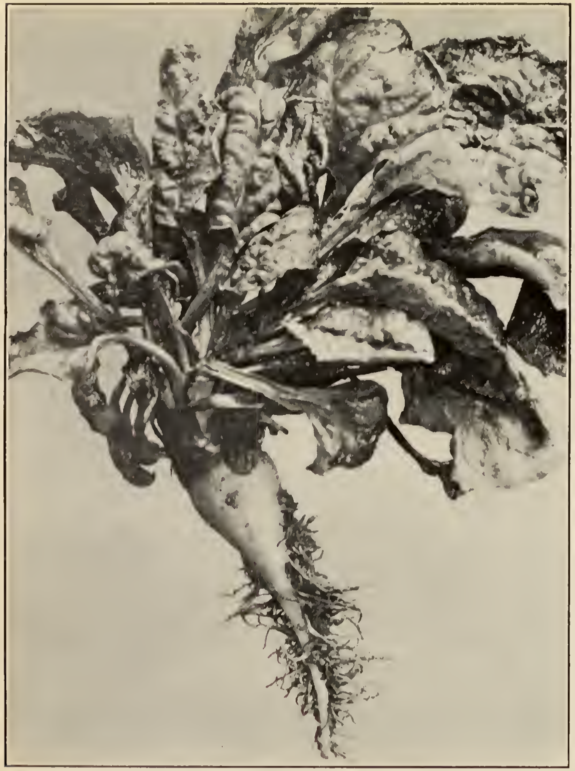


Fig. 1.—Large Sugar Beet Affected Late in the Season by Curly-top.

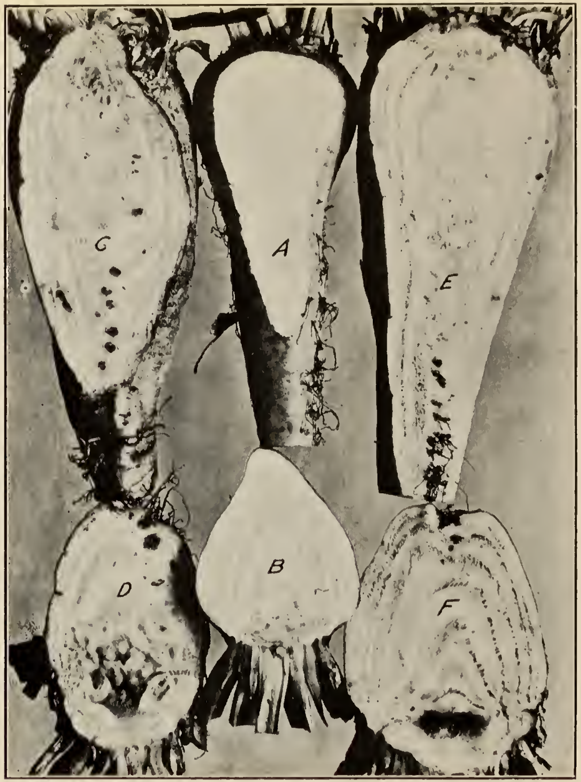


Fig. 2.—Sections of Healthy and Curly-top Sugar Beets, Showing the Discoloration of Fibro-vascular Bundles.

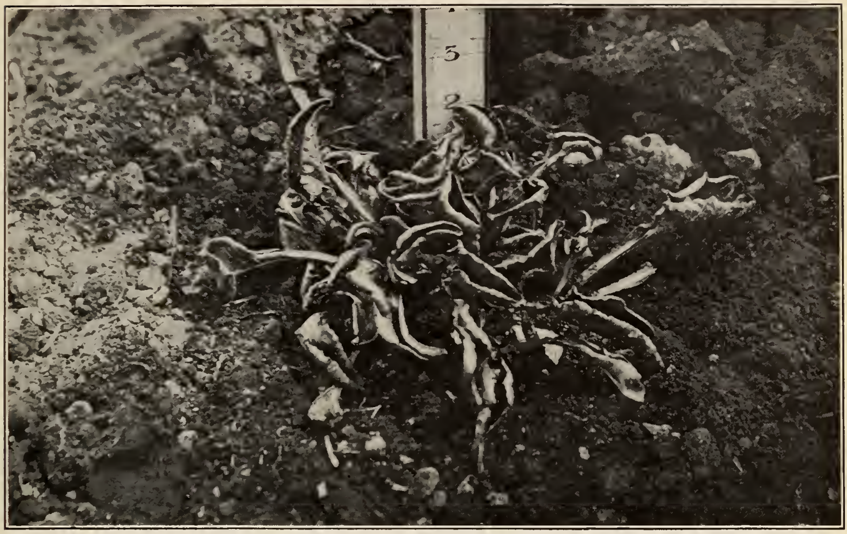


FIG. 1.—SEED BEET EXHIBITING INWARD TYPE OF CURL.

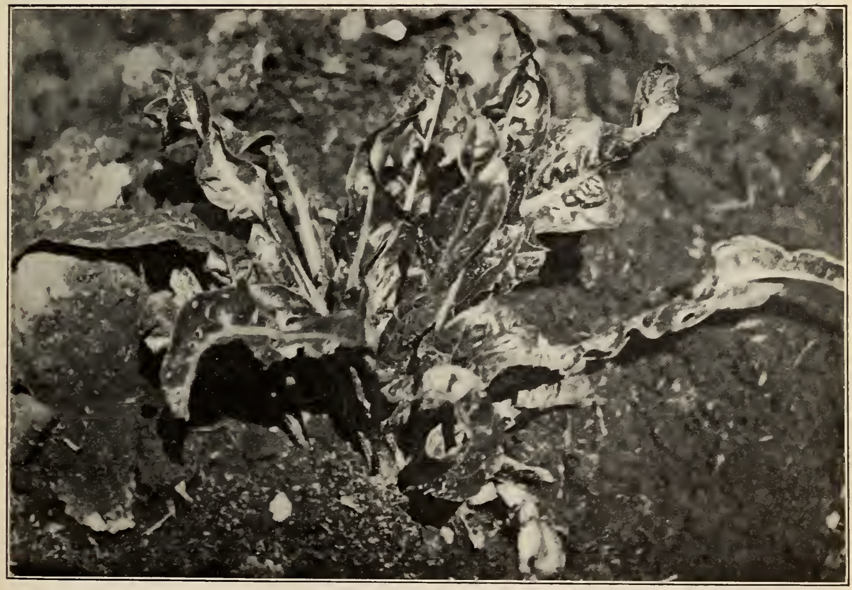


FIG. 2.—SEED BEET WITH LONG, SINUOUS TYPE OF LEAVES CAUSED BY CURLY-TOP.

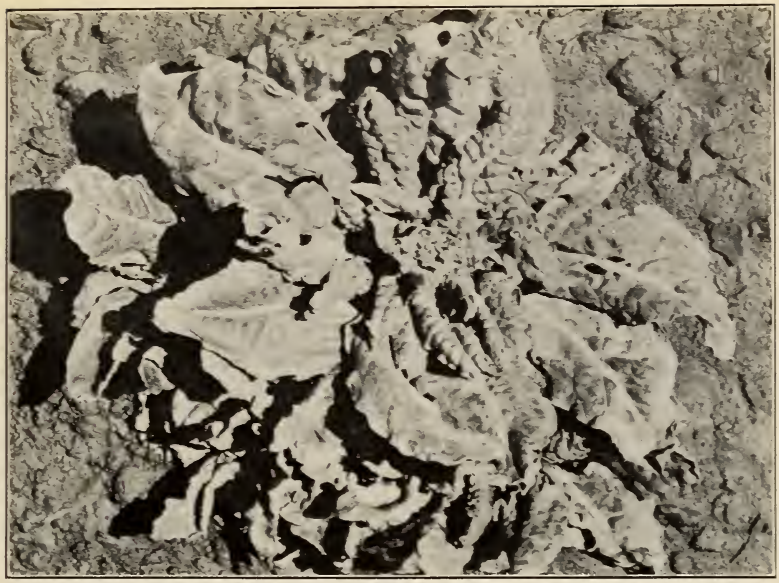


FIG. 1.—SEED BEET SHOWING RETRACTED TYPE OF CURL.

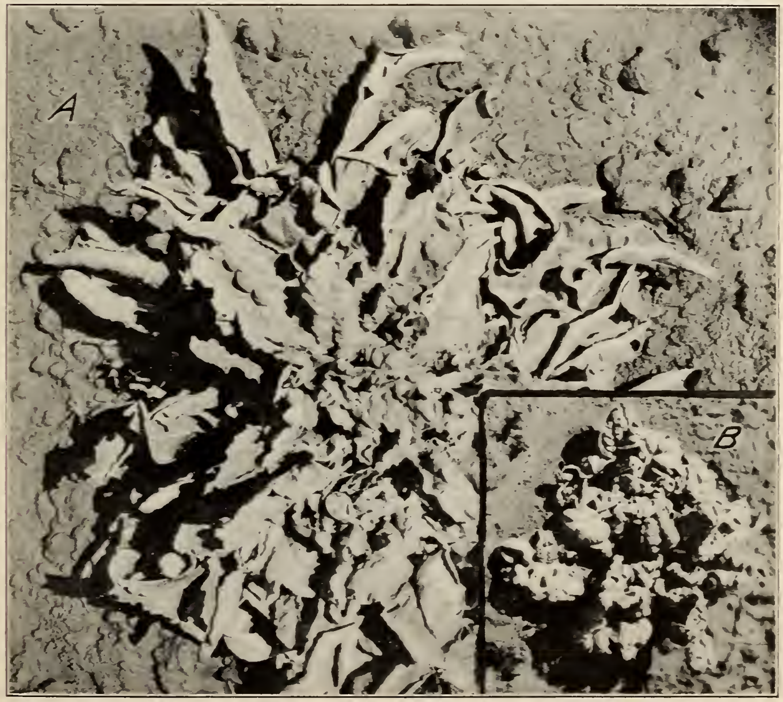


FIG. 2.—*A*, SEED BEET SHOWING BOTH INWARD AND RETRACTED TYPE OF LEAF-CURL; *B*, SEED BEET WITH ROSETTE OF SEVERELY RETRACTED LEAVES AND NO SEED STEM.

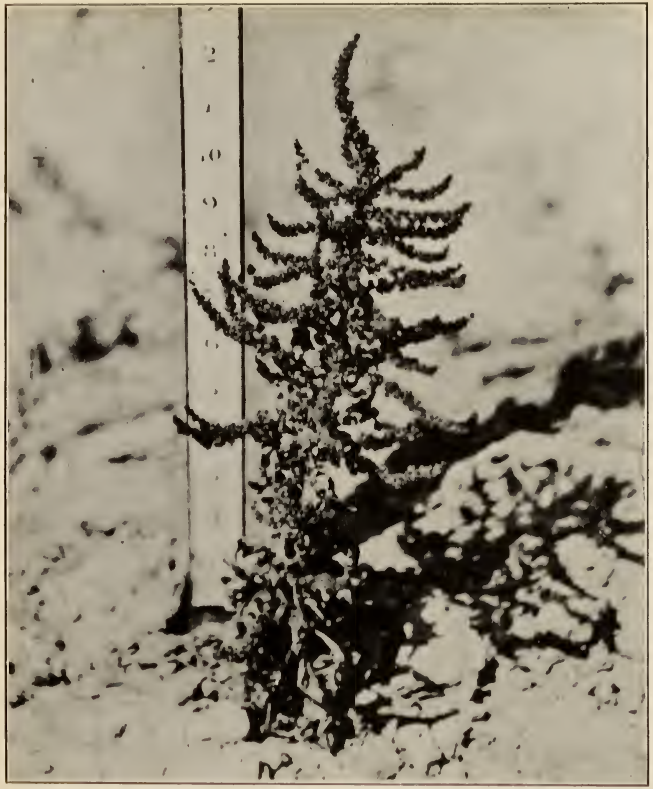


FIG. 1.—CURLY-TOP SEED BEET MATURING SEED.

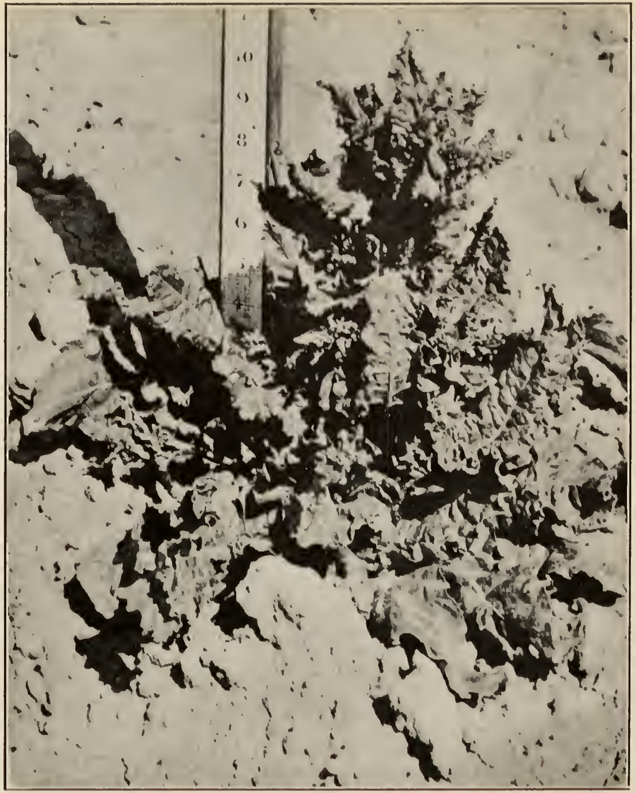
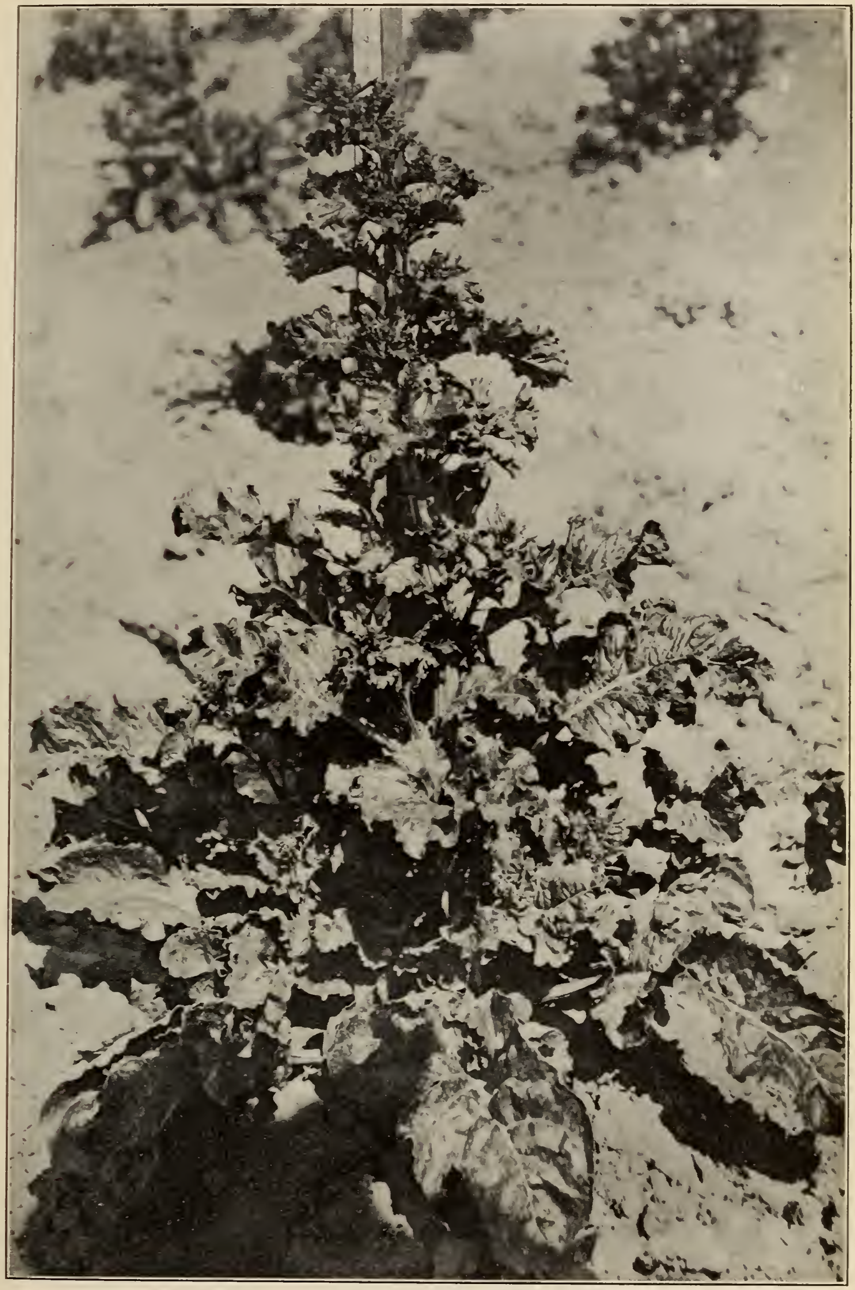


FIG. 2.—SEED BEET SLIGHTLY AFFECTED BY CURLY-TOP.



HEALTHY SEED BEET OF SAME AGE AS THAT SHOWN IN PLATE VI, FIGURE 2.

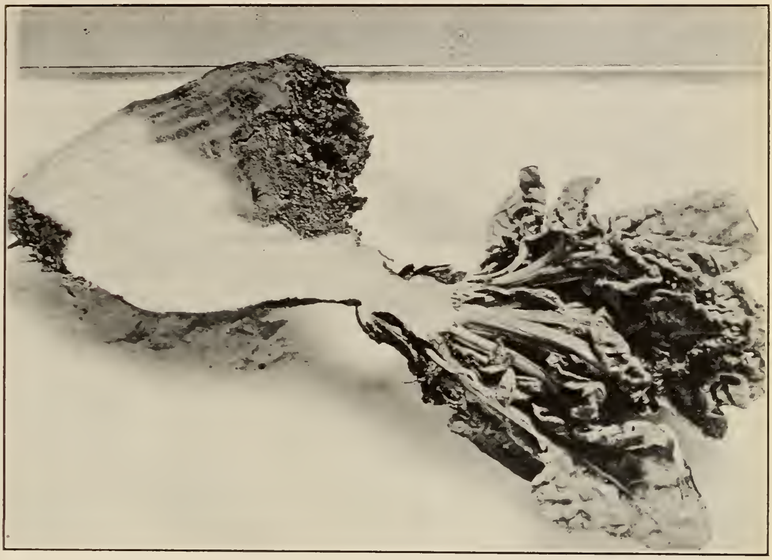


FIG. 1.—SEED BEET BADLY AFFECTED BY CURLY-TOP, AND ROOT ALMOST DESTROYED BY ROT.

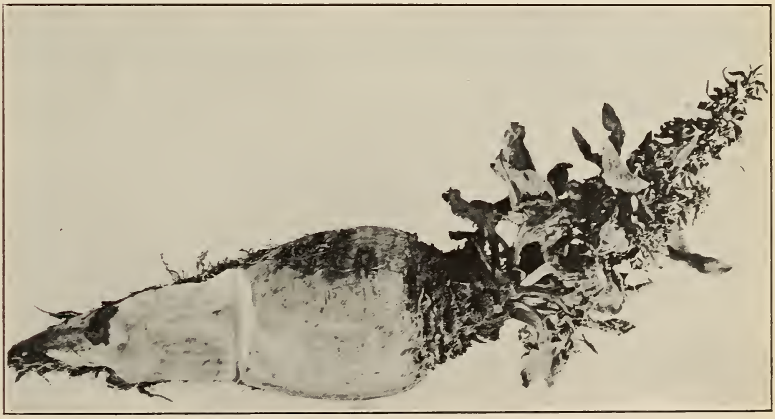


FIG. 2.—SEED BEET WITH SOUND ROOT, THOUGH BADLY AFFECTED BY CURLY-TOP.

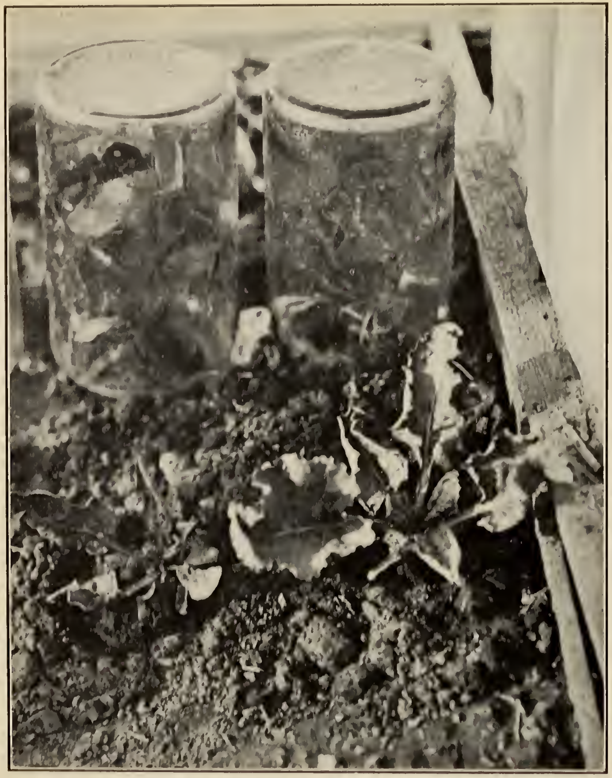


FIG. 1.—TWO YOUNG SUGAR BEETS SHOWING CURLY-TOP SYMPTOMS UNDER TEST CONDITIONS WITH LEAFHOPPERS.

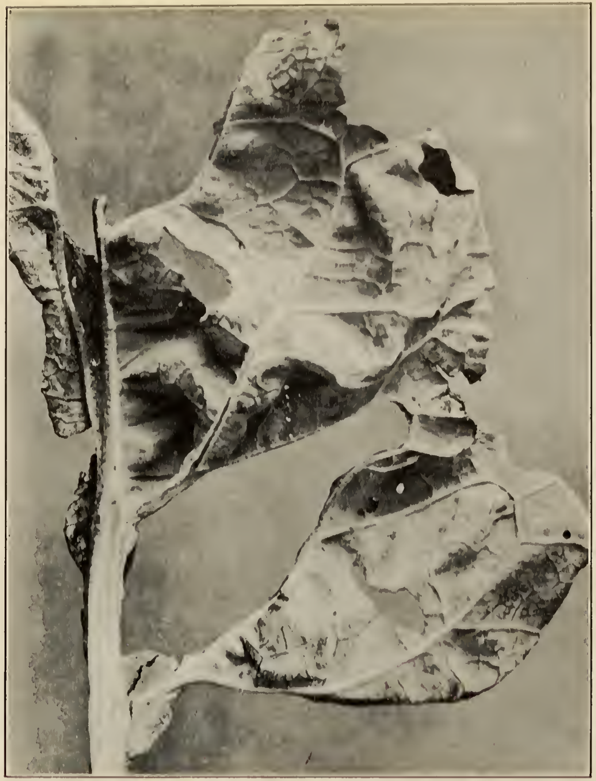


FIG. 2.—PORTION OF A CABBAGE LEAF SHOWING CURLY-TOP SYMPTOMS AFTER LEAFHOPPER ATTACKS; NO VISIBLE SPOTTING OF LEAVES.

INDEX.

Aleyrodes citri. *See* Fly, white. Page.
Aphides, damage to beet leaves, studies and experiments in Utah 14
    effect on apples and pears 31
        carnations 31
Apples, effect of aphides, thrips, etc 31
Atriplex sp., host plant of beet leafhopper 22
Bacteria, possible cause of curly-top in beets 13
Ball, E. D., study of beet leafhopper as cause of curly-top 13, 23, 24
Beet leafhopper. *See* Leafhopper, beet.
Beets, curly-top. *See* Curly-top.
    disease. *See* Curly-top.
    extraction of plant juices, responsibility for curly-top 20–21
    growers, importance of recognition of leafhopper 24
    injury caused by Eutettix strobi 21
    leaf-curl, types, symptoms, etc 28–29
    leaves, damage caused by aphides, studies and experiments in Utah 14
        leafhoppers, comparison of work of nymphs and adults 18
            studies and experiments in Utah. 14
        red spiders, studies and experiments in Utah. 14
        thrips, studies and experiments in Utah 14
    mother, use of term 12
    planting, early, advantages in prevention of curly-top 19–20
    rotting, caused by Phoma betae 13
        Rhizoctonia 13
    seed, curly-top, attack 24–25
            progeny healthy 31
            symptoms and description 12–13
        diseased, healthfulness of progeny 31, 32
        nonproduction of seed when affected by curly-top 29–31
        percentage of loss from curly-top 29–30
        production, damage to industry by curly-top 29–31
            menace of curly-top 9
        raising, effect of curly-top 24–28
        use of term 12
    spraying for control of leafhoppers 35
    sugar, attacks of hop flea-beetle, control 36
        contraction of curly-top 24–25
        initiation of curly-top by leafhoppers, study of time and manner. 25–28
        pedigree, planting in Utah 25
        selection for siloing 24–25
    whiskered, beet disease 9, 10
    young, destruction by curly-top 11

Page.
Bibliography of curly-top of beets 37–40
Blight, beet disease 9
    use of term 9
    western, beet disease 9
Brown, N. A., investigation of curly-top 18
Cabbages, Idaho, presence of beet leafhoppers 22
Cages, isolation, use in study of cause of curly-top in beets, description, etc 14–18
Carnation, effect of aphides, thrips, etc 31, 32, 33
Citrus trees. *See* Trees, citrus.
Cobb, N. A., study of stigmonoses 31, 33
Conclusion of bulletin 35–36
Curly-leaf, beets, use of term 9
    top, beets, bibliography 37–40
        cause 20–21
            experimental study in Utah 13–14
            studies and experiments 13–18
            theories 13
            use of isolation cages in study 14–18
        characteristics 31–33
        damage to beet-seed production 9
        description, causes, conditions, etc., summary of studies 33–35
        destruction of young beets 11
        influence of climatic conditions on severity of disease 34
        initiation of disease by beet leafhoppers, time and manner 25–28
        internal symptoms, description 11
        other names for disease 9, 10
        outbreak, effect of climatic conditions 21–22
            favorable conditions 21–22
            in Utah experimental field, history 18–19
        possible causes, list 13
        prevention, advantages of early planting 19–20
        relation to stigmonoses and mosaic 31–33
        resemblance to stigmonoses 31–33
        responsibility of leafhopper, studies and experiments 25–28
        seed, effect 24–28
            progeny healthy 31
            responsibility for nonproduction 29–31
            symptoms and description 12–13
        seriousness of disease 24
        similarity to mosaic 32
        successive outbreaks, improbability 31
        symptoms, description 9–13
            external, description 9–10
            vein, description 13
    See also Leafhopper.
Disease, beets. *See* Curly-top and Leafhopper.
Dock, food for leafhoppers in Idaho 21
Dondea sp., host plant of beet leafhopper 22
Emulsion, kerosene and whale-oil soap, use in control of leafhoppers 35
Entomology, Bureau, studies of beet leafhopper, with recommendations 35–36
Eutettix strobi, injury to beets 21
    tenella, host plants, list 22
    See also Leafhopper.

Page.
Flea-beetle, hop, comparison with beet leafhopper 36
  enemy of sugar beets, control, studies by Bureau of Entomology 36
Fly, white, damage to citrus trees 22
  description, habits, etc 22–23
  use of name for beet leafhopper in West 22
Fungi, leaves, possible cause of curly-top in beets 13
  roots, possible cause of curly-top in beets 13
Greasewood, host plant of beet leafhopper 22
Hairy-root, beet disease 10
"Hopper-dozer," use in control of beet leafhopper 35
Hosts, Eutettix tenella, list 22
Insects, possible cause of curly-top in beets 13
Introduction to bulletin 9
Irrigation, use in control of beet leafhoppers 36
Isolation cages. *See* Cages, isolation.
Jamieson, C. O., investigation of curly-top 18
Juices, plant, extraction not sufficient to account for curly-top in beets 20–21
Kerosene and whaleoil-soap emulsion. *See* Emulsion.
Leaf-curl, beets, seed and sugar, types and symptoms 28–29
Leafhopper, beet, comparison with hop flea-beetle 36
  description, habits, etc 22–23
  host plants 22
  initiation of curly-top in sugar beets, time and manner, study and experiments 25–28
  origin in southwestern United States 22
  probable cause of curly-top 13–18
  recognition, importance to beet growers 24
  responsibility for curly-top, studies and experiments 25–28
    summary of studies 33–35
Leafhoppers, beet, capturing, methods and devices 35–36
  control, cooperative experiments with Bureau of Entomology 35–36
    experiments in Colorado and Utah 36
    methods 35–36
    recommendations by Bureau of Entomology 35–36
    use of irrigation 36
  damage, preventive measures, control methods, etc 36
    to beet leaves, studies and experiments in Utah 14
  history, hibernation places, etc 35–36
  invasion, barriers, natural and artificial 22
  nymphs and adults, comparison of damage 18
    experiments by Office of Sugar-Plant Investigations 18
  presence on cabbages in Idaho 22
  See also Curly-top.
Leaves, beets. *See* Beets, leaves.
Moisture, abnormal supply, possible cause of curly-top in beets 13
Mosaic, beets, relation to curly-top 32, 33
Mother beets. *See* Beets, mother.
Moulton, study of stigmonoses 31, 33
Nymph, beet leafhopper, more harmful than adult 18

Page.
Parker, W. B., study of control of hop flea-beetle ... 36
Pears, effect of aphides, thrips, etc ... 31
Phoma betæ, responsibility for rotting of beets ... 13
Plant juices. *See* Juices, plant.
Planting, early, beets, advantages in prevention of curly-top ... 19-20
Plates, description ... 41
Red spiders. *See* Spiders, red.
Rhizoctonia, responsibility for rotting of beets ... 13
Rumex crispus, food for leafhoppers ... 21
Russian thistle. *See* Thistle, Russian.
Sarcobatus sp., host plant of beet leafhopper ... 22
Sea-blite, host plant of beet leafhopper ... 22
Seed, beet, poor, possible cause of curly-top ... 13
        production, menace of curly-top ... 9
    beets. *See* Beets, seed.
Siloing, sugar beets, selection ... 24-25
Soil, abnormal conditions, possible cause of curly-top in beets ... 13
Sowing. *See* Planting.
Spiders, red, damage to beet leaves, studies and experiments in Utah ... 14
Spraying, beets, use of emulsion in control of leafhoppers ... 35
Stigmonoses, resemblance to curly-top of beets ... 31-33
Sugar-Plant Investigations, Office, experiments with leafhoppers ... 18
Summary of bulletin ... 33-35
Thistle, Russian, host plant of beet leafhopper ... 22
Thrips, damage to beet leaves, studies and experiments in Utah ... 14
    effect on apples and pears ... 31
        carnations ... 31
Titus, E. G., study of beet leafhopper as cause of curly-top ... 13
Townsend, C. O., investigation of curly-top ... 18
        study of curly-top symptoms ... 32
Trees, citrus, damage by white fly ... 22
Utah, curly-top of beets, outbreak at Garland experimental field, history ... 18-19
            study of cause and experiments ... 13-14
    pedigree sugar beets, planting, experiments ... 25
Whaleoil-soap and kerosene emulsion. *See* Emulsion.
Whiskered beets. *See* Beets, whiskered.
White fly. *See* Fly, white.
Woods, A. F., study of stigmonoses ... 31, 32, 33

O

[Continued from page 2 of cover.]

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